INTERNATIONAL GEOLOGICAL CONGRESS

REPORT OF THE EIGHTEENTH SESSION
GREAT BRITAIN 1948

PART XIII (13)

PROCEEDINGS OF SECTION M

OTHER SUBJECTS

ALSO INCLUDING MEETINGS ON THE GEOLOGY AND MINERALOGY OF CLAYS

LONDON
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General Editor: A. J. Butler

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Edited by

R. M. SHACKLETON

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Section M, Other Subjects, met on six occasions during the Session: On August 25th, 26th, 27th, and 30th; and twice on August 31st.

Sir Edward Bailey was Chairman at all meetings except that of August 27th when Professor Léon Collet took the Chair.

The Secretary of the Section was Professor R. M. Shackleton.

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The Geology and Mineralogy of Clays

THE GEOLOGY OF IRON ORE DEPOSITS OF EGYPT

By M. I. ATTIA

Egypt

ABSTRACT

Iron and iron ores have occasionally been used by the Ancient Egyptians, and are now again receiving attention.

Iron-stained rocks abound in Egypt and iron ores are widely scattered. The iron ores may be classified according to mode of occurrence into:—1. Magmatic segregations; 2. Cavity fillings; 3. Metasomatic replacements; 4. Ore beds.

1. To this category belong the iron ore deposits in Wadi Abu Ghalaqa and Wadi Abu Garida in the Eastern Desert. In the former locality the ore is segregated from a coarse-grained gabbro, in the latter from a basic rock.

2. Iron ore deposits in the form of lodes occur in Wadi Meialik, Wadi Abu Garida, Wadi Abu Marwa and Wadi Dib in the Eastern Desert and in Gebel Abu Masaud in Sinai.

3. The manganiferous iron ores of south-western Sinai have been formed by metasomatic replacement of a Carboniferous dolomitic limestone.

4. Ore beds occur as:—(*a*) Pisolitic iron ore in Bahariya Oasis; (*b*) Oolitic iron ore in the famous locality east of Aswan; (*c*) Minor deposits of haematite and limonite in the Eastern Desert; (*d*) Detrital iron ore—the black (iron) sands on the Mediterranean Coast; (*e*) Bands interbedded with crystalline schists in Wadi Um Hagalig, Wadi Siwiqat Um Lasaf, and Wadi Um Heyut in the Eastern Desert; (*f*) Banks of ochre deposited from waters of artesian wells in Kharga and Dakhla Oases.

INTRODUCTION

THE Ancient Egyptians occasionally used iron and iron ores. This is proved by the finding of iron beads in some of the tombs and by the well-known piece of iron found in the inner joints of the Great Pyramid at Giza. The inscriptions on the Nubian Sandstone Stela which is situated on the north side of Wadi Abu 'Agag, 3·2 kilometres north of Aswan station, indicate that the iron ore of this area was worked by the Ancient Egyptians during the Eighteenth Dynasty.

Although iron ores in Egypt have thus been known from as early as the Eighteenth Dynasty (about 1580 B.C. to 1350 B.C.), they have not received much attention until lately. This is probably due to the absence of coal in Egypt and to the occurrence of favourably situated rich iron ores in other countries. Now that the scheme for generating electricity from the Aswan Dam is to be carried out, it is hoped that the iron ores—especially those near Aswan—will be utilized.

DISTRIBUTION OF EGYPTIAN IRON ORES

Iron-stained rocks abound in Egypt, and iron ores in the form of oxides are widely scattered (see Fig. 1).

In the Eastern Desert, iron ore deposits are widely distributed; up to now they are known to occur between latitudes 24° and 30° North, as described below. In the Western Desert, iron ore deposits are to be found in some of the oases, notably in Bahariya Oasis. In the Nile Valley, iron ore deposits are developed in the desert area east of Aswan; poorer deposits occur in desert regions bounding the valley between Aswan and Wadi Halfa. Black (iron) sands are deposited by the Nile on the Mediterranean Coast principally at Rosetta and Damietta. In the Sinai Peninsula, iron ore deposits occur in the western and southern portions.

CLASSIFICATION OF EGYPTIAN IRON ORE DEPOSITS

The Egyptian iron ore deposits may be classified according to their modes of occurrence:—

1. *MAGMATIC SEGREGATIONS*

Wadi Abu Ghalaqa Area.—In this locality titaniferous iron ore occurs in a conspicuous hill (24° 21′ 20″ N., 35° 03′ 30″ E.) formed of a medium- to coarse-grained gabbro. West of this hill is


MAP OF EGYPT
Showing the localities of the different modes of occurrences of iron ores
Magmatic Segregation
Cavity-Filling or Lodes
Metasomatic Replacement
Ore Beds
SCALE
20 0 20 40 60 80 100 120 140 160 180 200 220 MILES
26 East of Greenwich
MEDITERRANEAN SEA
RED SEA
HEJAZ
TRANSJORDAN
PALESTINE
LIBYA
SUDAN
GULF OF SUEZ
GULF OF AQABA
DEAD SEA
Ammân
JERUSALEM
Jaffa
Beersheba
Rafa
El 'Arish
El 'Auja
El Qusaima
Petra
Ma'an
Aqaba
El Kuntilla
Nekhl
Nuweiba
Dahab
Sherm
Tôr
Abu Zenima
Abu Durba
Zeitia
Western Sinai
Northern Galala
Zafarâna
Gebel Abu Mas'ûd
Wadi Dib
Hurghada
Porphyry Quarries
Safaga
Wadi Abu Marwa
Wadi Abu Garida
Atalla Mine
Quseir
Wadi el-Kereim
Wadi Um Gerifat
Wadi Um Hagalig
Wadi Um Lasaf
Barramia Mine
Sukari Mine
Sikait Mine
Ranga
Bîr Ranga
Wadi Abu Ghalaqa
Wadi Meialik
Berenice
Halaib
Oya Mine
Um el Tiyur Mine
Um Garaiyat Mine
PORT SAID
El Qantara
Ismailia
SUEZ
Zagazig
Mansura
Damietta
Baltim
Kafr el Sheikh
Rosetta
Tanta
Damanhûr
Shibin el Kôm
Benha
CAIRO
Giza
Helwân
Ghubbet el Bûs
Wasta
El Faiyûm
Beni Suef
Minya
Asyût
Sohâg
Qena
Qift
Luxor
Isna
Wadi Siwiqat Um Lasaf
Idfu
Kom Ombo
East Aswân
West Aswân
Aswân
Kalabsha
Garf Husein
El 'Allâqi
Offeduniya Temple
El Dirr
Kurusku
Abu Simbil
Adindân
Halfa
El Kharga
Baris
Dakhla Oasis
Gebel Ghorabi
El Bawîti
Qasr Farâfra
Maghra
ALEXANDRIA
El Hammâm
Dab'a
Fuka
Matrûh
Sidi Barrâni
Salûm
Siwa

FIG. 1.

the main granite range. Off-shoots from the granite penetrate the rocks of the hill as thin veins (up to 1 metre thick). Thin quartz veins are also seen cutting the gabbro. East of the hill the country is formed of diorite intruded by many basic dykes. The hill mass has been subjected to dynamic metamorphism and shows regular cleavage planes. The rocks of this area are of Pre-Cambrian age.

As a result of the intrusion of granite, some alteration has taken place in the gabbro as well as in the ore, producing leucoxene. There is no doubt that the ore is the result of magmatic segregation. Seven samples of the ore gave the following percentages of iron and titanium oxides:—

Titanium oxide ...	50·50	46·55	43·65	47·24	54·00	41·70	32·00
Iron oxide	34·75	36·95	36·40	36·75	40·00	51·84	54·22

The amount of ore in this locality is immense and may be some millions of tons. The deposit could be worked by open-cut and simple quarrying. The locality is about 20 kilometres from the Red Sea coast at Bir Ranga; it is either near, or the same as, the one near the well of El-Ranga described by W. F. Hume (1909).

Wadi Abu Garida Area.—In this locality (at about 26° 21′ N., 33° 20′ E.) there is an occurrence in which good haematite ore seems to be segregated from a basic rock. The mineral contains 67·20 per cent of iron oxide equivalent to 47·04 per cent of metallic iron. Impurity is mainly silica.

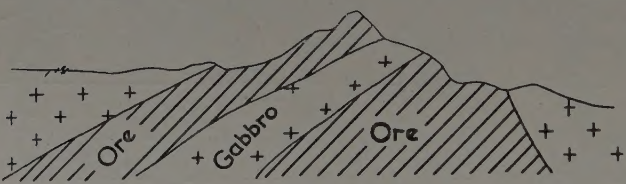

FIG. 2.—*Section showing magmatic segregation of ore.*

2. *CAVITY FILLINGS OR LODES*

Iron ore deposits belonging to this category occur in the Eastern Desert and the Sinai Peninsula in the following localities:—

Wadi Meialik Area.—In this locality (about 24° 10′ N., 35° 20′ E.), the country rock is diorite, decomposed in places. In parts of the area, the diorite is unconformably covered by a conglomerate formed mainly of various types of igneous rocks, or by a sandstone. Manganese ore, with subordinate iron ore, occurs in lodes varying in thickness from 0·25 to 1·25 metres.

The lodes strike roughly N.W.–S.E. and are either vertical or steeply dipping (60°–70°) towards the south-west. Some extend for a distance of 400 metres. They cut through the diorite as well as the conglomerate and the sandstone. Manganese oxide in places impregnates the country rock. The ore is mainly manganese oxide with haematite; at present only the manganese oxide is worked.

The genesis of the ore was by fissure filling from solutions arising from acid igneous rocks. The fact that the lodes traverse both igneous and sedimentary rocks proves the primary origin of the ore.

Wadi Abu Garida Area.—In this locality (about 26° 21′ N., 33° 20′ E.), micaceous haematite is associated with quartz veins cutting dioritic rocks. The mineral contains 82·40 per cent of iron oxide equivalent to 57·68 per cent of metallic iron.

Wadi Abu Marwa Area.—The country rocks in this locality (26° 30′ N., 33° 42′ E.) are diorites, etc.; they are cut by veins, filled with quartz and limonite or with siderite. The veins are related to the igneous intrusions. The iron ore is of poor quality and of no economic importance.

Wadi Dib Area.—In this locality (27° 50′ N., 32° 58′ E.), the country rocks, here granite, diorite, etc., are cut by veins filled with quartz and haematite or siderite. The veins are genetically related to igneous intrusions; they are of limited width and extent and of no economic importance.

Gebel Abu Masaud Area.—To the north-west of Gebel Abu Masaud, Southern Sinai (28° 25′ N., 34° 06′ E.), iron ores in the form of magnetite, micaceous haematite, or limonite occur in quartz veins cutting the granite. The occurrence here is of a lode-like nature; the width of the veins is small and the area is not easily accessible, so that the deposit is of no economic importance.

3. *METASOMATIC REPLACEMENTS*

The iron-manganese ores of South-Western Sinai are of this type. The area is near the western coast (29° 05′ N., 33° 20′ E.) of the peninsula; it covers more than 200 square kilometres.

The ores are closely connected with the Carboniferous limestone. The Carboniferous in this region consists of an upper sandstone (150 metres thick), a middle dolomitic limestone (40 metres thick) and a lower sandstone (130 metres thick). The lower sandstone rests directly on Pre-Cambrian gneisses, schists, granites and diorites; it is reddish, strongly cemented and dense. The limestone is very dolomitic, hard and crystalline; its colour is greyish near the top and reddish towards the base. The upper sandstone is soft and coarse-grained.

Tectonic movements have produced numerous folds, faults and fissures.

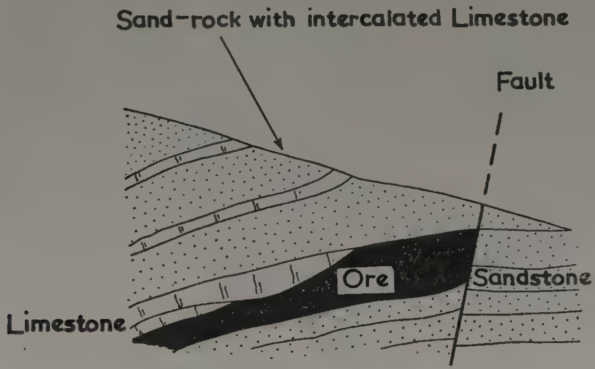

FIG. 3.—*Section showing limestone metasomatically replaced by ore.*

The ore in this region varies from a pure iron ore (haematite) to a pure manganese ore (pyrolusite, psilomelane, etc.) but is often a mixture of the two in various proportions. Rarely, traces of malachite are seen. The ores are found in the Carboniferous limestone, particularly in its lower part at the contact with the lower sandstone. They replace the limestone, often partially and rarely completely. They are always in intimate association with one of the numerous faults or fissures which traverse the region.

The ore bodies are irregular in form; they are often lenticular or spheroidal, especially those of pure manganese. The bodies of mixed iron and manganese ore are very numerous. They are more regular than the pure manganese deposits, and tend to be tabular; they also attain greater thicknesses varying from 4 to 10 metres.

The composition of the various types of ore is indicated by the following figures:—

Iron Ore.—The amount of iron oxide in this ore varies between 25·86 and 98·24 per cent, equivalent to from 18·10 to 68·77 per cent of metallic iron.

Manganese Ore.—The manganese oxide content of this ore varies between 30·33 and 86·80 per cent, equivalent to from 19·16 to 57·00 per cent of manganese.

Mixed Iron and Manganese Ore.—The iron oxide content of this ore varies between 16·90 and 34·24 per cent, equivalent to from 11·83 to 23·97 per cent of metallic iron; that of manganese oxide varies between 29·52 and 51·43 per cent, equivalent to from 18·66 to 37·18 per cent of manganese.

An average of about a hundred samples of the mixed ore gives: 35·00 per cent of manganese; 23·00 per cent of iron; 2·95 per cent of silica, and 0·14 per cent of phosphorus. The ore is a typical manganiferous iron ore. Impurities are silica, lime, magnesia, alumina, and traces of phosphorus and sulphur.

The genesis of the ore deposits.—It seems clear, for the following reasons, that the ores have been formed by metasomatic replacement of the dolomitic Carboniferous limestone:—They are confined to the easily dissolved dolomitic Carboniferous limestone; the ore bodies are regular in form, but often lenticular; the deposits are always connected with fissures or faults which served as channels for the mineral solutions coming from depth, and are thicker and richer close to faults or fissures.

4. *ORE BEDS*

(*a*) *Pisolitic Iron Ores*

The iron ore at Bahariya Oasis is of this type. The oasis is in the Western Desert (between 27° 48′ and 28° 30′ N., 28° 35′ and 29° 10′ E.). In the oasis, isolated hills composed of Cenomanian sandstones and clays are capped by dark, ferruginous grits and quartzites of the Oligocene formation; these are associated with pisolitic iron ore, limonite, and red and yellow ochre. The ore deposits are best seen at Gebel Ghorabi at the northern extremity of the oasis.

The Oligocene pisolitic iron ore has an average thickness of 4 metres; thin bands of limonite occur in the Cretaceous clays and sandstones. A sample of the pisolitic ore gave 58·70 per cent of iron oxide equivalent to 41·07 per cent of metallic iron. Three samples of limonite gave 84·00, 66·98 and 51·68 per cent of iron oxide equivalent to 58·80, 46·88 and 36·18 per cent of metallic iron.

The pisolitic character of the ore and the general nature of the beds indicate shallow-water, lacustrine deposition and precipitation. The bands of limonite in the Cretaceous clays and sandstones, which formed the floor of the lake, are probably due to infiltration of ferruginous solutions from above. The total amount of ore is probably very great but the locality is far from the sea and from the Nile Valley; and so remains at present undeveloped.

(*b*) *Oolitic Iron Ores*

The best occurrence of this nature is east of Aswan. The ore of this area was worked by the Ancient Egyptians. The area within which the iron ore deposits are scattered lies between 24° 03′ and 24° 14′ N. and 32° 52′ and 33° 22′ E., and has a length of about 50 kilometres from east to west, and an average breadth of 20 kilometres from north to south.

The main part of the area is underlain by sediments of the Nubian series which were laid down on a denuded, irregular surface of Pre-Cambrian schists, granites, etc. The sedimentary rocks are sandstones, quartzites, grits, conglomerates, clayey sandstones, shales and clays; some of the latter are refractory. A conglomerate is generally seen at the base of the series. The sandstones seem to have been deposited under shallow-water conditions, as indicated by cross-bedding and the lateral variations in lithology and thickness. Fossils are not common but a few found in the sandstones enclosing the iron ore indicate the Senonian age of this part of the Nubian series. The total thickness of the Nubian series, at the south-west corner of the area, is about 86 metres; but in some places it is nearly twice that amount. The middle beds contain two bands of good oolitic iron ore about two metres thick.

The refractory clays associated with the iron ore were worked in ancient times by means of long galleries. Above these clays there is a thin layer of oolitic iron ore, which thickens towards the east and the south, and is there represented by two bands of oolitic iron ore, each with a maximum thickness of about two metres, separated by a band of ferruginous sandstone.

Oolitic iron ore forms the ground surface over a large part of the area. Ferruginous concretions which occur in some of the sandstones have in places accumulated on the surface, giving it a black appearance.

Tectonics.—Away from faults, the strata are either horizontal or inclined at a very small angle;

on the whole there is a slight dip to the north. The dip is only steep near the faults. The principal faults have either north-south or N.W.–S.E. trends; a few run from east to west or from N.E. to S.W. Some have large throws and can be followed for long distances; others are only minor dislocations and cannot be traced far.

The Iron Ore.—The iron ore deposits form more or less regular beds which thin out to the east, west and south; to the north, where they disappear under the upper beds of the Nubian series, their extent is unknown.

The ore is a compact dark red oolitic haematite; it consists of spheres (1 to 1·2 millimetre in diameter) of haematite, cemented by an amorphous matrix of the same material.

The chemical composition of the ore varies from place to place; the main constituents are ferric oxide (Fe_2O_3) and silica (SiO_2). Analyses of a number of samples from the different localities indicate that the content of iron oxide in the ore varies between 54·80 and 88·10 per cent, equivalent to a range from 38·30 to 61·60 per cent of metallic iron. The iron oxide in the ore, therefore, averages 71·50 per cent equivalent to 50·00 per cent of metallic iron. The ore can be classed as a good quality ore. Sulphur is absent.

The ferruginous sandstones associated with the iron ore.—Several analyses have been made of different samples of these ferruginous sandstones. The iron oxide content varies between 30 and 54 per cent equivalent to from 21 to 38 per cent of metallic iron. Sulphur is present.

These ferruginous sandstones cannot be utilized, at least at present.

The ferruginous concretions.—Chemically, these resemble the ferruginous sandstones, but have a higher content of iron oxide. An average sample gives 58·80 per cent of iron oxide, equivalent to 41·13 per cent of metallic iron, and 34·22 per cent of silica.

Origin of the Ore.—From the above account, it can be seen that this oolitic iron ore is a sediment deposited from a concentrated solution. The deposition must have taken place in shallow water, most probably in a lake.

Amount of Ore.—Various estimates have been made of the quantity of the iron ore in the area but these vary very widely. Some authorities estimate it to be more than 300 million tons; for an accurate estimation further investigation and borings are needed.

This occurrence has been dealt with in some detail as it is the most important occurrence of iron ore in Egypt.

West of the Nile opposite Aswan, iron ore deposits occur in the Nubian series in the form of oolitic iron ore and ochre. These ore deposits are thin and seem to represent the western edge of the main ore deposit seen east of Aswan. The iron oxide content of the ore ranges from 26·00 to 78·95 per cent, equivalent to from 18·20 to 55·26 per cent of metallic iron. The quantity of ore is very limited.

(c) *Other Ores in Sedimentary Rocks*

Other iron ore deposits of sedimentary origin occur in the Nubian series between Aswan and Wadi Halfa at the following localities:—

At Jowikol, north of Kalabsha Cataract; a sample gave 34·80 per cent of Fe_2O_3, equivalent to 24·30 per cent of metallic iron.

At Garf Husein, west of the Nile; a sample gave 13·43 per cent of Fe_2O_3, equivalent to 9·40 per cent of metallic iron.

At Gebel Takkar, east of the Nile; a sample gave 22·96 per cent of Fe_2O_3, equivalent to 16·07 per cent of metallic iron.

At Offeduniya Temple, west of the Nile; a sample gave 42·46 per cent of Fe_2O_3, equivalent to 29·72 per cent of metallic iron.

At Kurusku, on the east bank of the Nile; a sample gave 31·70 per cent of Fe_2O_3, equivalent to 22·19 per cent of metallic iron.

At Abu Simbil, west of the Nile; a sample gave 34·54 per cent of Fe_2O_3, equivalent to 24·20 per cent of metallic iron.

Other occurrences of iron ores of sedimentary origin are:—

Iron Oxide and Pyrites near Bir Ranga.—This locality is three kilometres north-west of Bir Ranga (approximately 24° 24′ N., 35° 12′ E.). The deposits occur in Middle Miocene gypsum beds. The gypsum beds and the ore beds show an anticlinal fold, the axis trending N.W.–S.E., the limbs dipping from 10° to 15°. The ore deposits consist of iron oxides (haematite and limonite), pyrite and native sulphur. The iron oxide bands are irregular and thin. They have no economic importance.

Iron Ore in Wadi Um Gerifat Area (approximately 25° 35′ N., 34° 32′ E.).—The strata at this locality are of Middle Miocene age and rest on Pre-Cambrian schists. From top to bottom, they are composed of limestone, calcareous grit, marl, sandstone and conglomerate. They dip gently to the east. The iron ore is either haematite or limonite and is found mainly in the limestone and calcareous grit but also in the marl. A one-metre band of good quality haematite is seen to extend for about 20 metres. The ore has no economic value.

Iron Ore in Northern Galala Area (about 29° 23′ N., 32° 36′ E.).—A thin band of ironstone occurs in the Carboniferous series and is covered with debris except for a distance of about 20 metres. The ironstone gave 33·26 per cent of iron oxide, equivalent to 23·28 per cent of metallic iron. The ore is of sedimentary origin and is of no economic importance.

(*d*) *Detrital Iron Ores*

The black (iron) sands on the Mediterranean Coast of Egypt are in this category. They come from the upper reaches of the Nile, from the Sudan and Abyssinia. They are brought down by the annual Nile flood and carried out to the Mediterranean Sea by way of the Rosetta and Damietta branches. After subsequent concentration by under-current and wave-action the black sands are deposited on the Mediterranean Coast principally near the mouths of the river at Rosetta and Damietta.

The thickness of the black sand bands ranges from 10 to 60 centimetres. They consist of ilmenite 39 per cent, magnetite 22, zircon 10, garnet 10, silica 10, green sand 6, monazite 2, and rutile 1. In recent years, these sands have been utilized for their ilmenite and magnetite contents.

(*e*) *Iron Ore Beds of Sedimentary Origin, in Pre-Cambrian Crystalline Schists*

Iron ore deposits of this kind are found in the Eastern Desert in the following three localities:—

Wadi Um Hagalig Area (25° 15′ 30″ N., 34° 16′ 30″ E.).—This deposit occurs in a feature on the left bank of Wadi Um Hagalig, a tributary of Wadi Mubarak; it is 65 kilometres from Marsa Mubarak on the Red Sea. The country rocks are mainly schists (quartz-schists, epidote-schists, chlorite-schists, etc.). These schists strike N. 23° W. and are inclined at angles of 60° to 80° towards the south-west. The iron ore occurs in numerous bands intercalated in the schists; these bands vary in thickness from 0·10 to 6·40 metres and can be traced for more than 2 kilometres.

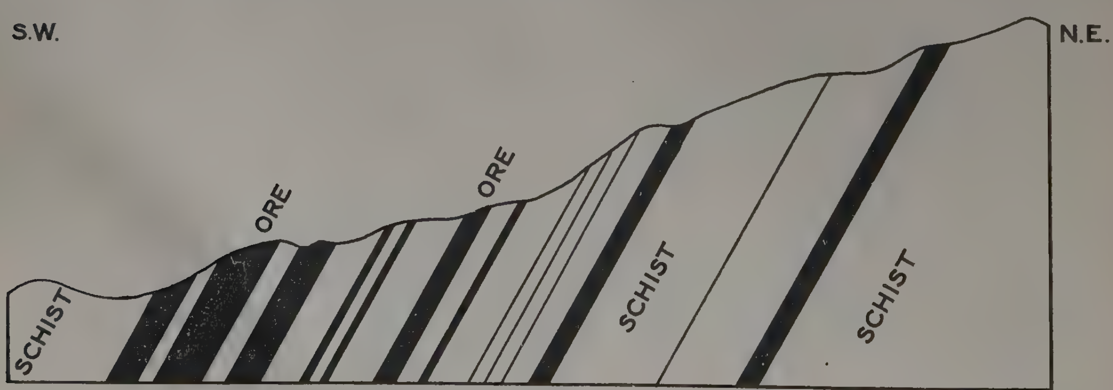

FIG. 4.—*Section showing Iron Ore bands interbedded with schists.*

The iron ores are magnetite-quartz-schists. Their iron oxide content varies between 56·60 and 77·60 per cent, equivalent to from 41·00 to 56·25 per cent of metallic iron. The silica content ranges between 19·00 and 34·51 per cent. The quantity of ore is great; the silica content is on the whole high.

The schists containing the iron ores are undoubtedly of sedimentary origin and are Pre-Cambrian in age. The iron ores must have been deposited with the ancient sediments, and their present character is due to subsequent metamorphism.

Wadi Siwiqat Um Lasaf Area (approximately 25° 21′ N., 34° 08′ E.).—The country rocks of the area are mainly schists (chlorite-schist, quartz-chlorite-schist, slates, etc.). The strike of these schists varies between N. 60° W. and N. 75° W.; they dip 14° to 18° towards the north-west. The iron ore occurs in bands interbedded with the schists; the bands vary in thickness from 0·35 to 4·50 metres.

In this locality there are four features in which the iron ore is found; the features range in height from 50 to 150 metres and in extent from 100 to 600 metres.

A specimen analyzed from this locality gave 75·40 per cent of iron oxide, equivalent to 52·79 per cent of metallic iron. The quantity of ore is great.

Wadi Um Heyut Area (25° 56′ 30″ N., 34° 01′ 30″ E.).—At this locality the iron ore deposits occur in a group of isolated features on the left bank of Wadi Um Heyut, a tributary of Wadi el-Kereim; it is 42 kilometres from Quseir on the Red Sea. The country rocks are mainly slates, chlorite-schists, etc.; their strike varies from N. 60° W. to N. 77° W.; they dip at 50° to 88° towards the north-east. The iron ore occurs in numerous bands in the schists; these bands vary in thickness from 0·30 to 17·00 metres and can be traced for a distance of one kilometre. In general the iron bands run parallel to one another; a trachy-andesite dyke which intersects them displaces them about 500 metres. The ore is a magnetite-quartz-schist. Its iron oxide content varies between 61·00 and 85·60 per cent, equivalent to from 44·15 to 62·00 per cent of metallic iron. The silica content varies between 15·00 and 32·46 per cent. The quantity of ore is fairly great.

(*f*) *Iron Ores deposited at Artesian Wells*

Iron ore deposits, in the form of oxides, especially red and yellow ochres, occur in Kharga and Dakhla Oases near several of the artesian wells. Ferruginous artesian waters have deposited thick banks of ochre along the channels leading from the wells into the fields. The deposition of the ochre takes place owing to the liberation of the gases dissolved in the artesian waters. The iron ore deposit is recent in age and is of excellent quality.

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THE STATISTICAL NATURE OF THE PROCESS OF FORMATION OF SEDIMENTARY BEDS

СТАТИСТИЧЕСКИЙ ХАРАКТЕР ПРОЦЕССОВ ФОРМИРОВАНИЯ ОСАДОЧНЫХ ТОЛЩ

By V. V. BELOUSOV

(В. В. Белоусов.)

U.S.S.R.

ABSTRACT

1. A correlation of the geological sections of sedimentary deposits with the process of recent sedimentation reveals certain incongruities which at first sight seem to contradict the principle of uniformitarianism.

The different facies of the sediments now in the process of formation show an irregular distribution on the bottom of the basin depending on the different physical-geographical conditions, on which the rate of accumulation of recent sediments and their thickness are likewise dependent.

In geological sections, on the contrary, a regular bedding and a greater scale in the distribution of facies are observed, while the thickness of the deposits is determined by the amount of downwarping of the earth's crust.

2. The author accounts for this lack of correspondence by the fact that between the moment of the original deposition and their final fixation in the section, a long process of redistribution of the sedimentary material is operative, caused by permanent oscillations of the earth's crust. A grading of the material takes place. The effect of local and temporary physical-geographical conditions upon sedimentation is subsequently eliminated.

3. In this way the recent sedimentation represents a detached phenomenon of short duration, while a geological section is the result of a statistical summing up and averaging of a complex set of phenomena.

Геологический разрез состоит главным образом из слоев горных пород, образовавшихся из различных морских и континентальных осадков. Так как осадки накапливаются как на дне моря так и на поверхности материков и в наши дни, естественно сопоставить условия залегания и распределения современных осадков, с одной стороны, и тех древних осадочных пород, которые мы видим в обнажениях, с другой. Принцип актуализма подсказывает, что при этом можно будет отметить если не полное тождество, то очень большое сходство между условиями залегания современных и древних осадков.

Однако, между строением геологического разреза и распределением осадков в современных морских и материковых водных бассейнах имеются существенные различия, которые часто игнорируются. Эти различия состоят главным образом в том, что строение геологического разреза обычно гораздо проще, однороднее, чем строение современных осадочных толщ.

Наблюдая распределение современных осадков как на дне морских бассейнов, так и на материках, мы видим очень пеструю картину. Характер осадков и форма их залегания быстро меняются от места к месту в зависимости от глубины дна, течений, температуры воды, выноса обломочного материала с прилегающих возвышенных областей, крутизны берега и т.д. Изменение этих факторов от места к месту вызывает постоянную смену на площади песков глинами, глин — известняками, различных осадков — участками вовсе лишенными их и т.д. В формах залегания современных осадков характерна зависимость их от рельефа. Мы видим заполнение осадками впадин, нагромождение рыхлых осадков шлейфами у подножья возвышенностей, прислонение к склонам, локализацию в пределах глубоких долин и т.п.

В разрезах древних геологических напластований такая пестрота, такое разнообразие осадков на малой площади наблюдается лишь в виде исключения. Обычно геологический разрез характеризуется своей однородностью на больших площадях. Пласты песков, глин, известняков, конгломератов прослеживаются, почти не меняя своего облика, на огромных протяжениях, исчисляемых сотнями километров по разным направлениям. Изменение же характера отложений в разрезах происходит обычно постепенно и закономерно.

Широкое распространение однородных осадков, наблюдаемое в разрезе, часто вступает в противоречие с тем, что мы знаем об условиях их образования. Галечники образуются в узкой прибрежной зоне шириной всего в несколько десятков метров, повторяющей изгибы берега. Казалось бы, и древние конгломераты должны обнаружить тот же характер залегания. На самом деле, в разрезах обнаруживаются обычно не полосы или линзы конгломератов, а слои их, раскинувшиеся на площадях в тысячи и десятки тысяч квадратных километров.

Такое же несоответствие проявляется в отношении таких осадков, как уголь, соль, гипс.

Уголь образуется в лагунах, отшнуровавшихся от моря и подвергшихся опреснению. Каждая лагуна имеет сравнительно небольшую площадь и ограничена от открытого моря и соседних лагун песчаным валом. В лагунах же образуются и соли.

Исходя из условий накопления растительного материала и соли в настоящее время, мы стремимся искать следы лагунной обстановки и в формах залегания древних угленосных и соленосных толщ. Мы ожидаем встретить уголь и соль всегда в форме изолированных небольших пятен с различным разрезом в пределах каждого пятна.

Хотя такое строение угленосных и соленосных толщ иногда наблюдается, в большинстве случаев отмечается иное : угленосные и соленосные свиты, сохраняя один и тот же разрез, прослеживаются непрерывно на очень больших площадях.

В геологическом разрезе не обнаруживается той сложности в залегании пород, которая зависит от рельефа : вместо неправильных нагромождений, форма которых определяется неровностями почвы, в геологическом разрезе мы видим ровные слои, ограниченные обычно гладкими параллельными поверхностями. Признаки погребенного древнего рельефа почти отсутствуют. Создается впечатление, что рельефа не было, когда образовывались слои, и что последние отлагались на выравненной горизонтальной поверхности. Однако, грубообломочный характер некоторых отложений указывает на то, что во время их образования должен был существовать расчлененный рельеф.

Известно, что в современных условиях быстрота накопления осадков весьма различна в зависимости от физико-географических условий. У устьев быстрых потоков, стекающих с крутых берегов, очень быстро нагромождаются большие массы грубого обломочного материала. Низменные берега почти не разрушаются и отложение осадочного материала около них происходит медленно. Кораллы возводят свои постройки очень быстро и коралловые рифы в своем росте перегоняют накопление известняков других типов. Быстрота накопления осадков зависит от рельефа, морских течений, характера берега, солености воды, ее температуры и т.д. В связи с этим, мощность осадков, образующихся в наши дни, колеблется от места к месту столь же сильно, как и фации. При этом наблюдается близкая зависимость мощностей осадков от их состава, от их фации, поскольку в современной обстановке и фацин осадка и мощность его определяются одним и тем же фактором — физико-географическими условиями отложения.

Еще раз, основываясь на принципе актуализма, мы предполагаем встретить сходную простую зависимость мощности осадка от физико-географических условий его отложения, т.е. обнаружить связь между мощностью осадка и его составом, его фацией. Мы полагаем, что в пределах одного стратиграфического подразделения грубообломочные осадки

должны отличаться всегда большей мощностью, чем тонкие, коралловые известняки должны иметь преимущество в мощности по сравнению с другими известняками и т.д.

Внимательное изучение распределения мощностей древних осадочных толщ снова выявляет несоответствие между действительностью и предположениями. Распределение мощностей древних отложений, входящих в состав геологического разреза, оказывается независимым от состава осадков, от их фаций, т.е. от местных физико-географических условий их образования. Исследование разрезов показывает, что план распределения больших и меньших мощностей одновременных отложений оказывается значительно более устойчивым, чем нлан распределения фаций. Фациальный план меняется, а план распределения больших и меньших мощностей сохраняется в течение длительного времени почти неизменным или же медленно меняется, но по своим собственным законам, независимым от расположения областей занятых осадками разного состава.

Изучая, например, разрезы Среднего и Нижнего Поволжья, мы легко устанавливаем, что для огромного отрезка геологического времени — от верхнего девона до верхнего мела включительно — Поводжье было местом накопления более мощных осадков, чем соседние области, разположенные непосредственно к западу и востоку отсюда. В качестве места, где также постоянно в течение палеозоя и мезозоя образовывались относительно более мощные толщи, можно указать и Подмосковный бассейн.

Между тем, на протяжении времени от девона до конца мела характер осадков, их фации, менялись многократно и резко. Известняки сменялись гипсами, последние — красноцветными континентальными отложениями, далее следовали морские пески и глины, снова известняки, угленосные отложения, мел и т.д. и т.п. И все эти разнообразные породы, образовавшиеся первоначально в самых различных физико-географических условиях, подчиняются в распределении своих больших и меньших мощностей одной и той же схеме. Сопоставление карт фаций с картами распределения мощностей показывает, что границы фациальных зон, испытывая постоянные смещения, как правило, не зависят от распределения мощностей и пересекают линии равных мощностей самым различным образом.

Очевидно, в этих условиях говорить о зависимости мощности от местных физико-географических условий не приходится. Если накопление в Поволжье более мощных, чем в соседних областях, юрских песчано-глинистых свит можно было попытаться объяснить благоприятным положением этой области по отношению к дававшим обломочный материал участкам суши, то конечно, нельзя тем же фактором объяснить накопление в той же зоне мощных верхне-меловых известняков и мергелей или гипсово-доломитовой свиты пермской системы. Совершенно невероятно, чтобы резко различные физико-географические факторы действовали так согласованно и места более быстрого и более медленного накопления осадков длительно оставались неизменными. В неисчислимое количество раз вероятнее, что бы с каждым изменением состава осадков, с каждым смещением фациальных зон, соответственно менялся и план распределения мощностей, чего на самом деле нет.

Изучение истории геосинклинали Большого Кавказа обнаруживает то же явление: в этой области план распределения больших и малых мощностей устойчиво сохраняется в течение юры, мела и палеогена, вопреки многократным и значительным изменениям фаций осадков. Например, полоса относительно больших мощностей на северном склоне Кавказского хребта остается таковой для песчано-глинистой толщи нижкей и средней юры, и для коралловых известняков мальма, и для песков и глин нижнего мела так же, как для мелоподобных мергелей и известняков верхнего мела и разнообразных пород палеогена.

Аналогичные примеры могут быть найдены где угодно и составляют общее правило.

Все эти несоответствия между респределением фаций и мощностей в осадках сейчас образующихся на поверхности Земли, с одной стороны, и фиксированных в геологическом разрезе, с другой, говорят, конечно не о том, что в смысле условий отложения современная эпоха отличается от предыдущих, а о том, что в геологическом разрезе мы видим уже не первичное распределение фаций и мощностей, характеризовавшее осадок в момент первоначального его отложения, а новое разпределение, явившееся результатом какого то преобразования осадочных толщ, происходящего в процессе их накопления и формирования геологического разреза.

Рассмотрение характера этих преобразований лучше всего начать с освещения вопросов, касающихся образования конечных мощностей осадочных свит. Для простоты ограничимся морскими отложениями, хотя нетрудно показать, что аналогичный механизм формирования мощностей существует и для большинства тех наземных отложений, с которыми мы встречаемся в геологических разрезах.

Существенным является то, что в геологических разрезах на поверхности современных материков мы имеем дело исключительно с осадками мелких шельфовых морей с глубинами, едва ли превышавшими 200 метров. Но дно мелкого моря является местом не только накопления, но и разрушения. Хотя и медленно действующим, но зато постоянным и повсеместным, а потому и основным, фактором разрушения являются волновые колебания частиц воды, вызываемые ветром. Хотя такие колебания с глубиной быстро ослабевают, они все же в открытом море достигают глубины до 200 м. Значение этой предельной глубины проникновения волн то, что осадки могут устойчиво накапливаться только ниже ее, а весь рыхлый материал, оказавшийся выше этой глубины, подвергается перемыванию и передвижению по дну волновыми течениями туда и сюда, пока не будет сброшен в какое либо достаточное углубление дна.

Представим себе, что в данной области моря все пространство возможного устойчивого накопления глубже уровня проникновения волн оказалось заполненным. Это значит, что материал, вновь сносимый сюда, не будет устойчиво накапливаться и все время будет передвигаться по дну с места на место. Новый материал получит возможность закрепиться в разрезе лишь в том случае, если произойдет опускание земной коры и под уровнем проникновения волн откроется новое пространство спокойной воды. Если прогибание, как обычно, происходит неравномерно, в одном месте больше, в другом меньше, то, естественно, осадочный материал в меньшем количестве остается на относительно менее погруженных участках и большей частью сталкивается теми же колебаниями воды в места более опущенные.

В этом и состоит в грубой схеме механизм, связывающий размер мощности морской осадочной толщи, закрепленной уже в геологическом разрезе, с размером прогибания земной коры. Накопление происходит в обстановке неравномерного прогибания земной коры; верхним пределом накопления является глубина проникновения волн, представляющая собой поверхность практически горизонтальную; под ней происходит перераспределение осадочного материала таким образом, что он своей мощностью компенсирует размер прогибания в каждом пункте. В процессе перераспределения первичное неправильное нагромождение осадков на дне водоема, вызванное действием многих местных физико-географических факторов, утрачивается. Фактор погружения земной коры действует, в какой то мере, конечно, и в отношении накопления современных осадков. Но в современной обстановке, когда мы имеем дело с короткими промежутками времени, этот медленно действующий фактор остается незаметным. Наоборот, выступают на первый план разнообразные, быстро меняющиеся, но и быстро действующие местные физико-географические влияния. Когда мы переходим к геологическому разрезу, где отпечатались события большой продолжительности, мы видим, что время очистило

процесс от влияния единичных изменчивых явлений и обнажило основной геологический фактор, определяющий мощности — размер прогибания земной коры.

Факт компенсации прогибания накоплением неоспорим, так как при любом размере мощностей мы наблюдаем в геологических разрезах всюду мелководные отложения. Он подтверждается и той устойчивостью плана распределения больших и малых мощностей, о которой говорилось выше: если бы компенсации не было, и мощности образовывались бы вне связи с размером прогибания земной коры, то такая устойчивость распределения мощностей былабы невозможно.

Кстати, следует указать, что та же длительная устойчивость рисунка линий равных мощностей и независимость этого рисунка от состава и происхождения осадков окончательно решает в отрицательном смысле вопрос о возможности истолкования прогибания земной коры как следствия тяжести накапливающихся осадков: размер накопления является следствием, а не причиной прогибания земной коры.

Конечно, компенсация прогибания накоплением не является математически точной. Глубины древних бассейнов менялись и это показывает, что накопление то несколько отставало от прогибания, то несколько его опережало. Такие отклонения возможны в результате изменения глубины проникновения волн при длительном изменении топографии бассейна, в результате изменения количества приносимого материала, и т.д., но наблюдения показывают, что размер отклонений весьма невелик: если огромное большинство морских осадков, обнаруживаемых в разрезах, образовалось на глубине не более 200 м, а континентальные осадки тех же разрезов представлены преимущественно отложениями низменных аллювиальных равнин, дельт и озерных водоемов, уровень которых едва ли превышал больше чем на 100 м уровень моря, то, следовательно, колебания поверхности осадков, запечатленные в строении геологических разрезов, не превышали по амплитуде нескольких сотен метров. По сравнению с размером мощностей осадочных толщ эти колебания настолько незначительны, что для первого приближения можно говорить о достаточно близкой компенсации прогибания накоплением.

Эта компенсация осуществляется не только перераспределением рыхлого материала по дну в соответствии с колебаниями земной коры, но и заполнением пространства возможного устойчивого накопления путем образования некоторых органогенных или химических осадков на самом месте прогибания. Во всяком случае наблюдения убеждают, что в пределах шельфовых бассейнов осадочного материала того или иного состава всегда оказывается достаточным для заполнения пространства возможного накопления. Эта закономерность отсутствует в океанических впадинах. Поскольку на современных материках осадков океанических глубин мы не обнаруживаем, для геологической практики случай океанов пока в этом направлении не имеет значения.

Обратимся теперь к механизму формирования того распределения вещественного состава осадков, который наблюдается в геологических разрезах и который, как мы видели, отличается от распределения его среди современных осадков. Условно мы назовем этот механизм механизмом образования фациальных зон.

Движущей силой и в этом случае являются волновые колебания воды, перемывающие осадочный материал.

Распределение фаций в геологическом разрезе и характер фациальной зональности определяются: (а) местоположением областей размыва и отложения и, в связи с этим, местоположением отдельных фациальных зон, зависящих от расстояния от берега; (б) шириной отдельных фациальных зон и прежде всего шириной разноса обломочного материала; (в) степенью сортировки осадочного материала по размеру зерна.

Распределение областей поднятия и прогибания обуславливает расположение мест размыва и накопления. Области размыва сопровождаются каймой обломочных осадков,

распределенных, в результате сортировки по грубости зерна, в виде фациальных зон, сложенных осадками все более тонкими по мере удаления от берега. На еще более далеком расстоянии от последнего образуются осадки не-терригенные, преимущественно — различные известняки. Эта схема нарушается, когда детритусовые известняки, состоящие из обломков раковин, играют роль обломочных пород и накапливаются ближе к берегу, чем тонкие терригенные осадки.

С перемещением береговых линий вместе с ними смещаются и фациальные зоны таким образом, что отложения различных фаций перекрывают друг друга, в трансгрессивной или регрессивной последовательности. При трансгрессии моря происходит срезание затопляемой суши и слои отлагаются на выровненной, как правило, горизонтальной поверхности. Рельеф суши таким образом не сохраняется. В своеобразном выражении он отражается в веществе самих слоев: например, слои, образующиеся там, где существовал резкий рельеф, содержат более грубый материал и т.п.

В результате такого смещения вслед за перемещением берега, свита (или слой) образованная осадками одной фации, в разных местах имеет различный возраст, формируясь постепенно в процессе движения берега. Нередко такую разновозрастность того или другого фациального комплекса удается подметить палеонтологическими методами. Тогда говорят о миграции фаций во времени и в пространстве.

Особый интерес представляют не менее частые случаи, когда перемещения берега происходят настолько быстро, что раньше, чем органический мир успел испытать заметную эволюцию, берег уже совершил значительное перемещение в одном направлении или даже ряд колебаний взад и вперед. В этом случае слой нам будет казаться одновозрастным образованием на всей площади своего отложения, тогда как на самом деле он является следом от перемещения берега. Это истолкование процесса слоеобразования позволяет понять многие случаи широкого распространения в разрезах таких пород, которые по условиям своего образования должны были бы наблюдаться лишь в виде узких полос. Таково распространение, например, конгломератов, наблюдаемое часто на огромных площадях. Очевидно, что такое их распространение обусловлено не тем, что течения разносили гальки на огромной площади, а береговая линия оставалась неподвижной, а тем, что берег перемещался и ковер конгломератов развертывался вслед за ним. В каждый момент галечник образовывался, как он образуется на берегах и современных морей, в узкой прибрежной зоне, но вместе с движением берега сдвигалась и эта зона и галечник постепенно покрывал все большую площадь. В этом же явлении состоит во многих случаях причина широкого распространения на площади и иных осадков, как обломочных, так и известняковых. Этим же объясняется приведенный выше пример с угленосными и соленосными фациями. Последние в каждый данный момент образуются в пределах отдельных небольших лагун, но в условиях постоянных вертикальных колебаний земной коры очертания лагун быстро меняются и в конце концов лагунные осадки, закрепленные в разрезе, покроют всю площадь, в пределах которой мигрировали отдельные лагуны и у нас может сложиться впечатление от изучения разреза, что здесь существовала одна огромная лагуна, на дне которой всюду одновременно образовывались соответственные осадки.

Та ширина отдельных фациальных зон и прежде всего ширина разноса обломочного материала, которая наблюдается в геологическом разрезе, также определяется процессом преобразования первичных отложений на дне моря. В механизме этого преобразования снова играют ведующую роль волновые колебания воды и глубина их проникновения. Так как в конце концов, в результате перемывания, весь обломочный материал, поступающий с суши, должен разместиться в пределах пространства возможного накопления ниже глубины проникновения волн, то ширина зоны, в которой устойчиво накопится этот материал, будет, очевидно, зависеть от скорости приноса обломочного материала и от

скорости прогибания земной коры в области накопления. Чем больше приносится материала, тем на большей площади он распространится в процессе перемывания волновыми колебаниями при постоянной скорости прогибания земной коры. С другой стороны, при постоянной скорости приноса обломочного материала замедление прогибания земной коры в области накопления создаст необходимость для этого материала распространиться в пределах более широкой зоны, так как пределом окончательного его накопления сверху остается та же глубина проникновения волн, а толщина пространства возможного накопления теперь меньше. Наоборот, убыстрение прогибания земной коры в области накопления приведет к сокращению ширины окончательного разноса обломочного материала, который найдет теперь для себя достаточный объем внутри пространства возможного накопления поблизости от берега.

Если мы учтем, что скорость приноса обломочного материала с суши означает скорость разрушения последней, а скорость разрушения определяется, как основным фактором, скоростью поднятия земной коры, то можно будет заключить, что ширина разноса обломочного материала зависит прямо от скорости поднятия земной коры в области размыва и обратно от скорости прогибания ее в области накопления, то-есть — от отношения этих двух скоростей. Вместе с изменением ширины всей зоны обломочных отложений меняетсят естественно, ширина и отдельных частных фациальных зон, образуемых, например песками, глинами и т.д.

Таким образом мы находим еще один механизм разноса осадочного материала на площади. Вместе с тем, постоянно наблюдаемую пульсацию ширины фациальных зон мы толкуем как результат постоянных изменений отношения между происходящими одновременно и рядом друг с другом поднятиями земной коры. Такие пульсации представляют собой один из случаев образования слоистости и вообще чередования осадочных пород разного состава в вертикальном разрезе. Другой случай мы рассмотрели выше в связи с вопросом о перемещении берегов. Оба эти случая обычно проявляются совместно. Т.е. фациальные зоны смещаются в связи с движением берегов и в то же время ширина их то увеличивается, то уменьшается.

Наконец, степень сортировки обломочного материала также определяется режимом колебательных движений земной коры.

Совершенство сортировки зависит от того, насколько долго и устойчиво она происходила в одном и том же месте и в одном направлении. Таким образом, четкое разделение осадков в геологическом разрезе по грубости зерна с образованием четкой фациальной зональности отражает устойчивое взаимное расположение областей размыва и отложения, устойчивость их границ. Если же эти границы неустойчивы, постоянно и далеко смещаются, причем смещения их происходят быстрее чем осадок успевает в процессе прогибания земной коры опуститься глубже уровня проникновения волн и закрепиться в разрезе, то интенсивность сортировки, ее место и направление в отдельных местах меняются, что путает картину распределения фаций, смешивает осадки различных фракций и ведет в конечном счете к фациальной расплывчатости и фациальному однообразию геологического разреза. Таким образом случаи наибольшего фациального однообразия в разрезах свидетельствуют о наибольшей неустойчивости режима колебательных движений земной коры, об обстановке, в которой области размыва возникают на короткое время то там, то здесь, быстро меняют свои очертания и то и дело уступают свое место областям отложения.

Такой неустойчивый режим является вообще характерным для платформ с их малым контрастом между восходящими и нисходящими движениями. Поэтому на платформах фациальные зоны всегда более расплывчаты, чем в геосинклиналях. Но и в этих последних такой же неустойчивый режим проявляется в некоторые переломные моменты (переход от преобладания опусканий к преобладанию поднятий с одновременной перестройкой плана расположения зон поднятия и прогибания обычно на обратный).

Подводя итоги всему изложенному, мы приходим к заключению, что геологический разрез обладает очень важным свойством: закрепленное в нем распределение фаций и мощностей осадков отнюдь не рисуют нам физико-географическую обстановку поверхности земли для какого либо отдельного кратковременного отрезка времени. Оно не

является фотографией существовавшего в некий конкретный момент времени состояния земной поверхности, ее топографии. Фации и мощности осадочных толщ отражают режим движений земной коры, усредненный за какой то промежуток времени, неизвестной для нас продолжительности, но несомненно, значительно более продолжительный, чем, скажем, наша человеческая история.

Действительно, мы видели, что окончательные мощности отложений определяются размером прогибания земной коры. Но такая зависимость не устанавливается сразу, в момент первичного отложения осадка: она возникает как результат перемывания осадков, в процессе которого роль местных и временных факторов, влиявших в отдельные моменты на скорость накопления, путем их взаимного наложения и суммирования нейтрализуется, а проявляется влияние другого более постоянного фактора.

Когда мы наблюдаем в геологическом разрезе слои, образованные перемещением берега, мы снова заключаем, что этот разрез не дает нам картину неподвижного распределения физико-географических условий в определенное и короткое былое время. Слои запечатлевают не статику, а кинематику этих условий и прежде всего кинематику перемещения берега. Наблюдая конгломерат в основании трансгрессивной серии, можем ли мы установить место берега, около которого этот конгломерат отлагался в какой либо определенный момент? Эта задача невыполнима. В разные моменты берег находился в любом месте в пределах площади распространения конгломерата, но где именно в тот или иной момент — сказать невозможно. Все, что можно заключить из наблюдения это то, что в течение такого то геологического века берег совершал колебания в пределах таких то границ. Возможно, что мы укажем еще и общее направление смещения берега. Мы можем установить, следовательно, лишь среднее положение берега для какой то, иногда довольно длительной эпохи.

Особенно ярко суммирующая и усредняющая роль геологического времени проявляется в сортировке осадочного материала в процессе колебаний земной коры. Как указывалось, при быстрых колебаниях расположение фациальных зон, отвечающее какому то определенному расположению участков поднятия и опускания, не закрепляется в разрезе. Раньше, чем оно успеет закрепиться, оно уже претерпевает изменение и в конце концов в разрез переходит картина распределения осадочного материала, являющаяся результатом усреднения всех частных колебаний, отражающая некоторое среднее состояние земной коры, не отдельные колебания ее, а их общий режим.

Таким образом формирование геологического разреза определяется закономерностями статистического характера. Они основываются не на единичных явлениях, которые обычно ускользают от наблюдений геолога, а на результатах их усреднения и суммирования, выраженных в одновременно происходящих и сложно сочетающихся между собою смещениях фациальных зон, изменении их ширины, сортировке и смешивании осадков, образовании конечных мощностей свит. Эти закономерности нельзя рассматривать как результат простого арифметического складывания единичных процессов: в ряде случаев геологическое время, усредняя частные явления, вносит в конечное выражение процесса качественно новое содержание. Оно вскрывает то, чем сумма геологических явлений принципиально отличается от каждого единичного явления, взятого порознь. Последнее особенно ярко проявляется в процессе формирования конечных мощностей отложений, когда последние определяются иным фактором (размером прогибания земной коры) по сравнению с теми временными, единичными, мгновенными мощностями, которые обусловливаются местной физико-географической обстановкой отложения.

Мы должны поэтому уточнить наше отношение к палеогеографическим построениям. Пользуется общим распространением взгляд, что палеогеографическая карта ничем принципиально не отличается от карты географической. Различие предполагается лишь количественное, сводящееся к меньшей точности палеогеографии по сравнению с картографией современного земного лика.

Этот взгляд только потому не привел пока к недоразумениям, что палеогеографические схемы, составляемые сейчас, весьма грубы и общи. Когда мы стремимся восстановить

среднюю картину распределения суши и моря для целой геологической эпохи, то это как раз то, что может быть из разреза извлечено. Но если бы мы захотели значительно уточнить наши схемы и строить их для очень кратких отрезков времени, соизмеримых с продолжительностью образования отдельного слоя, мы оказализь бы в затруднении: все устойчивые вехи ускользнули бы от нас. Мы убедились бы, что составление палеогеографических карт по тому принципу, на котором основаны карты географические, невозможно, что мы имеем дело с вещами качественно различными. Спустившись к отдельным слоям, мы утратили бы возможность нащупать устойчивое положение берегов и могли бы указывать лишь общее направление и амплитуду их смещений.

Поэтому простота очертаний суши и моря, характерная для палеогеографических карт, является следствием не только одного несовершенства таких карт. Сложные очертания современных берегов представляют собой единичное, мгновенное явление, имеющее преходящее значение, тогда как на палеогеографических схемах фиксируется лишь некоторое среднее, обобщенное положение берега, суммарный результат многих единичных его колебаний.

Распределение осадочных толщ в геологическом разрезе в вертикальном и горизонтальном направлении точно так же отражает, как мы видели, не единичное состояние земной поверхности, а средний режим колебательных движений земной коры и усредненное распределение физико-географических условий, не отвечающее их распределению в какой либо определенный момент.

Здесь заложено принципиальное различие между геологичёскими науками, с одной стороны, и физической географией, геоморфологией, океанографией т.е. науками, изучающими современный облик Земли, с другой. Последние науки имеют дело с единичными явлениями, которые изучаются каждое отдельно. Они имеют дело с обстановками, которые в перспективе геологического времени являются мгновенными и неподвижными. Геология занимается суммарными и средними результатами единичных явлений, их кинематикой. Поэтому изаконы, выводимые этими двумя группами наук, могут быть иногда качественно различными, так как между единичными движениями земной коры и общим их режимом может быть не больше общего, чем между движением отдельной молекулы и движением всего тела.

Это не значит, что мы хотим разделить стеной указанные науки и уничтожить связи между ними. Мы стремимся лишь показать, что взаимоотношение этих наук много сложнее, чем обычно предполагается. Оно выяснится, когда мы научимся понимать закономерности, связывающие единичные физико-географические явления с их геологической суммой.

Наконец, несколько слов о применимости принципа актуализма.

Основываясь на последнем, геолог, восстанавливая процессы прошлого, исходит из предпосылки, что силы, действовавшие на нашей планете в былые эпохи, ничем существенно не отличались от тех сил, которые проявляются сейчас. Отсюда — возможность непосредственного применения результатов наблюдений над современными процессами к объяснению событий, запечатлевшихся в строении земной коры.

По существу это обобщение не может возбудить сомнений. Нет никаких оснований полагать, что в течение эпох, доступных изучению геологическими методами, на земле проявлялись силы, теперь отсутствующие. Но это не значит, что указанный принцип может применяться к истолкованию геологического разреза столь упрощенно, как это часто бывает.

Никакие особые силы на Земле в прошлые эпохи не проявлялись. Но геологический разрез не фиксирует результаты первичных процессов: он является продуктом преобразований, благодаря которым единичные процессы скрадываются, а в строение разреза вносится качественно новое начало — статистическое обобщение. Это начало, неизвестное современным геологическим образованиям, вносит большое различие между современной обстановкой и тем выражением условий прошлых эпох, которое запечатлелось в разрезах. Понимание последнего должно усложнить, но в то же время и обогатить содержание стратиграфии, палеогеографии, литологии, учения о фациях.

SUR L'INCONSTANCE DU DÉJETTEMENT TECTONIQUE DANS LA ZONE OROGÉNIQUE ANATOLIENNE

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RÉSUMÉ

Dans les diverses zones structurales du système des Alpides en Asie Mineure, le déjettement tectonique (" Vergenz ") comme résultat de la poussée principale est variable. La grande courbure du Taurus sudanatolien comporte une succession d'écailles, couronnée d'une nappe, le tout faisant face au Sud; toutefois, ce mouvement unilatérale est contrebalancé par des éléments structuraux dans la Région des Lacs et regardant le Nord.

L'opposition est même encore plus frappante dans l'aile Est de ce système où les écailles constituant la haute chaîne de l'Aladağ vent vers l'intérieur, tandis que les chaînes successives à l'Est, séparées d'elle par une zone ophiolithique, trahissent la poussée vers l'Est, qui est aussi dominante dans le bord de Maraş-Andirin (charriage). Passant vers le Nord dans la courbure estanatolienne, la variabilité s'accuse dans la préponderance des éléments déversés au Nord et une poussée subordonnée au Sud.

Progressant au Secteur du Taurus limitrophe à l'Irak et à l'Iran une disposition analogue au Taurus occidental se présente en tant que le bord Sud charrie en écailles le " Vorland," tandis que dans la zone de Van, située au bord intérieur de premier massif ancien, le déversement va au Nord.

Une inconstance similaire, mais moins soulignée par une poussée exagérée, s'accuse aussi dans l'aile nordanatolienne. Dans une large zone limitrophe à la masse intérieure et centrale, moins engagée dans le paroxysme alpin, des anticlinaux asymétriques ou des faibles charriages, regardant le Sud, existent, allure qui se prétend par endroits loins vers le Nord. Ce n'est que dans la zone pontique, où localement des écailles interfèrent, que le déversement vers le Nord est mieux souligné.

La raison de cette variabilité dans la structure régionale et locale est complexe et dépend particulièrement de la répartition des résistances en quoi la position où la participation d'un soubassement ancien joue un rôle important.

POUR exprimer l'asymétrie d'un pli à l'égard de la direction de la poussée prédominante et immédiate qui l'a crée, on parle d'un déjettement ou déversement ou, si l'on se sert de l'expression introduite par H. Stille, de la "Vergenz". Il existe une longue file de transitions entre un simple pli asymétrique et la forme tectonique résultant d'une poussée exagérée et produisant une écaille ou nappe de charriage. En vérité, l'expression d'un déjettement s'applique mieux au pli simple, mais en étant l'effet de la même force orogénique ou mieux tectogénique, je voudrais ici l'élargir à tous les accidents tectoniques résultant d'une force latérale prédominante (pli déversé, massif asymétrique, écaille et nappe de charriage). Une coordination du caractère et de la répartition relative de ces accidents tectoniques nous instruit sur l'action des mouvements en jeu, leur force et leurs relations mutuelles, locales et régionales.

On sait que les Alpides se composent d'une aile septentrionale et méridionale dont le schéma habituel est que la première, les Alpides, proprement dites, est déjetée dans ces éléments structuraux au Nord, tandis que ceux de la seconde, les Dinarides, font face au Sud ou à une direction correspondante. La zone orogénique alpine entre en Asie Mineure avec une vaste ampleur; ce qui est reserré et superposé dans les Alpes occidentales est ici élargi et juxtaposé, de façon que le jeu des mouvements s'épanouit plus libre et devient plus complexe. On a distingué dernièrement (Arni, 1939; Egeran 1947; Blumenthal, 1945) des longues zones longitudinales d'étendue régionale dont les Pontides et les Anatolides constituent l'aile Nord et les Taurides et les Iranides l'aile Sud, tandis que les Irakides jalonnent le bloc arabique. Entre les deux ailes régionales s'étend une zone intermédiaire qui a moins subi les mouvements alpins (Leuchs, 1943; Blumenthal, 1946; Egeran, 1947).

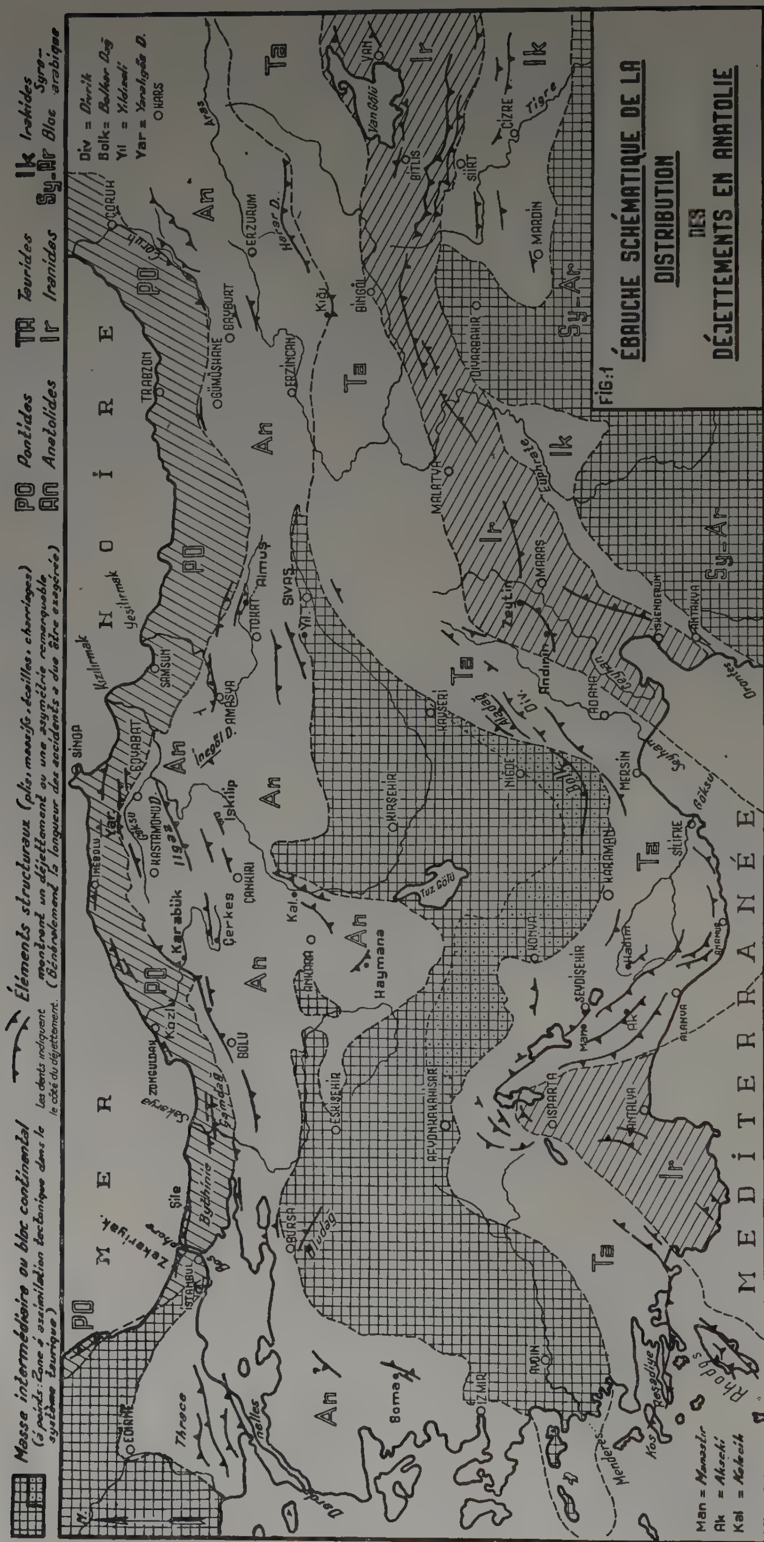
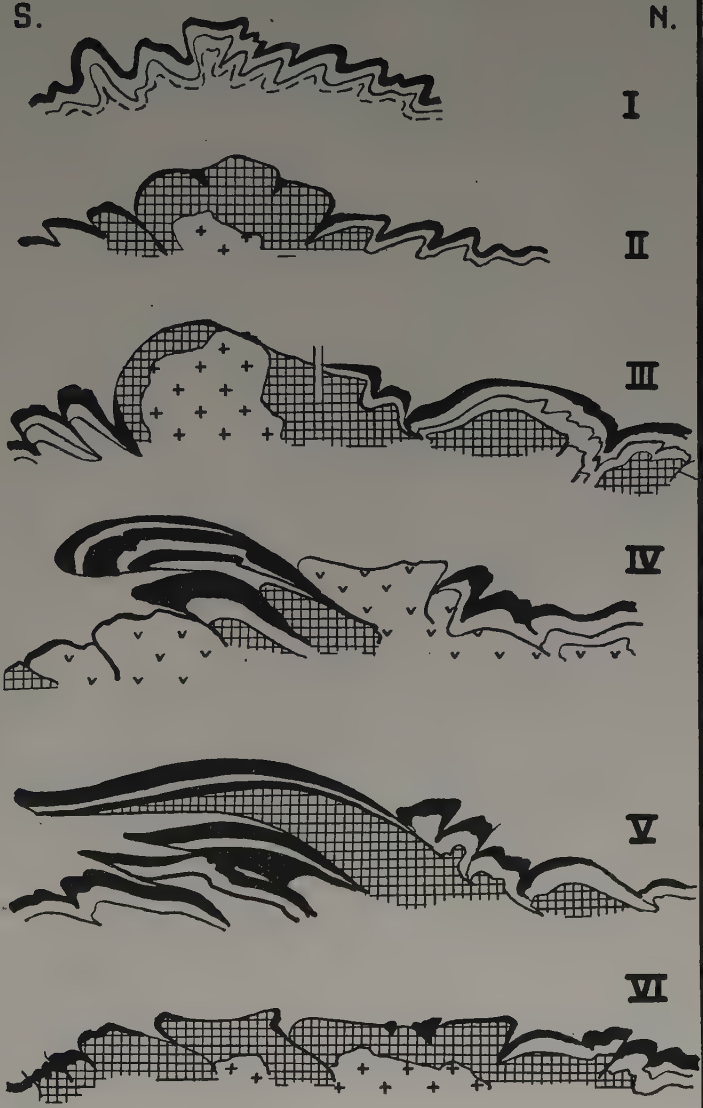


FIG: 1 ÉBAUCHE SCHÉMATIQUE DE LA DISTRIBUTION DES DÉJETTEMENTS EN ANATOLIE

FIG. 2

QUELQUES TYPES D'UNE ALLURE TECTONIQUE RÉGIONALE

À DÉJETTEMENT OPPOSÉ



Noir et lignes = *Série mésozoïque et tertiaire*
Carré = *Soubassement paléozoïque ou cristallin*
Croix = *Massifs de granit ancien*
Crochets = *Massifs (ou coulées) volcaniques ± syntectoniques*

(Explication dans le texte)

Dans ces diverses zones longitudinales le résultat de la poussée orogénique est loin de correspondre au schéma déjà mentionné. Une inconstance bien prononcée regne dans la zone orogénique anatolienne en ce qui concerne le sens du déversement des éléments structuraux de façon qu'il y a nombre de cas où des déjettements en sens opposé se rangent de part et d'autre d'une zone axiale visible ou supposée. À l'état actuel des recherches géologiques il n'est pas encore possible d'établir partout le caractère du plissement, le sens de la " Vergenz." Si j'ose en faire quand-même un bref inventaire en tenant compte surtout des plissements alpins, cela ne peut être fait qu'à titre préliminaire; et en faisant l'ébauche d'un croquis (Fig. 1) je soumets son amplification et sa rectification au progrès futur.

Dans le but d'orienter l'esprit d'or et déjà, je désire de discerner une série de cas embrassant de divers types de déjettement tectonique en sens opposé; ils peuvent se traduire dans les dispositifs suivants (Fig. 2):—

I. Dispositif tectonique à déjettement opposé englobant des simples plis de couverture (Zone pontique, Thrace).

II. Dispositif tectonique montrant le déjettement opposé par rapport à un massif plus ou moins debout et jalonné symétriquement de plis ou d'écailles (Massif de Bitlis).

III. Dispositif tectonique accusant l'opposition d'un déversement inégal en forme de massifs profonds ou de plis de fond, ceux-ci occasionnellement remplacés ou suivis de plis déversés ou d'écailles (Massif de Bolu-Écailles du Çamdağ; Soubassement carbonifère de Camli; Massif de l'Ilgaz Dağ; Plis d'Inebolu et du Yaraligöz Dağ).

IV. Dispositif tectonique montrant un déjettement opposé à envergure inégale, mais symétrique par rapport à une zone de roches intrusives (Aladağ, Taurus occidental à Manastir-Huglu).

V. Dispositif tectonique embrassant des ailes inégales opposées, d'une part un pli de fond charriant, d'autre part des plis ou des écailles de faible profondeur (Taurus occidental dans la région Akseki-Göksu Irmak).

VI. Dispositif embrassant des plis de fond de part et d'autre et montrant des déjettements opposés (Massif Tokat-Amasya).

Si maintenant, à l'aide de la nouvelle Carte géologique de la Turquie (Blumenthal, 1946) nous voulons faire un voyage hâtif le long des grandes zones distinguées au début et tendant de faire ressortir la répartition des divers déjettements tectoniques, il est préferable de partir du Nord-Ouest où la connexion avec les pays balkaniques est le moins intercepté par la mer. Le déjettement au Nordest et au Nord, conforme au Balkan bulgare proprement dit, est apparent. Dans les Pontides de la Turquie on remarque, s'appuyant de leur côté intérieur sur le Massif d'Istranea en Thrace, ou sur le soubassement ancien de la Bythinie en divers points, l'existence de plis déversés ou même des écailles à caractère de plis de fond et repartis sur une distance longitudinale d'environ 100 km. Ceci est un trait tectonique remarquable [Zekeriyaköy (Chaput, 1931); Şile (Baykal, 1943; Paréjas, 1940)]. Vu l'extension longitudinale notable, il est plausible que cette allure tectonique se prolonge dans la direction de la côte de Zonguldak et vers la région des Pontides plus orientales. Mais l'asymétrie y devient plutôt faible et hésitante, ne se traduisant que dans le bord Nord occasionnellement plus raide de la zone élevée du Paléozoïque (Carbonifère) de Zonguldak (Camli) (Arni, 1931). Au delà de la courbure d'Inebolu un déjettement net à l'extérieur dans les Pontides n'est que local. Par contre, arrivant plus à l'E.S.E., dans la vallée du Göksu près de Boyabat, ligne qui sépare à une certaine distance les Pontides des Anatolides, quelques accidents tectoniques démontrent même des petits chevauchements vers le Sud (Blumenthal, 1942, 1948). Le cas étrange se présente donc que la zone qui devrait être la plus prédisposée au déjettement au Nord, caractérisant l'aile septentrionale des Alpides, épouse, dans son bord méridional, le retour au Sud, tandis qu'il n'y a que de petits plis de couverture jalonnant la Mer Noire qui montrent un faible déversement de ce côté. Si l'on veut classifier cette allure tectonique, elle ressemble au Cas I s'approchant du Cas III, puisqu'il y a au Sud un massif ancien qui participe.

La même volte-face existe encore plus à l'Est dans la vallée du Kelkit Çay et du Yeşil Irmak. Le long de la première ligne je croyais pouvoir interpréter une partie de la grande dislocation du

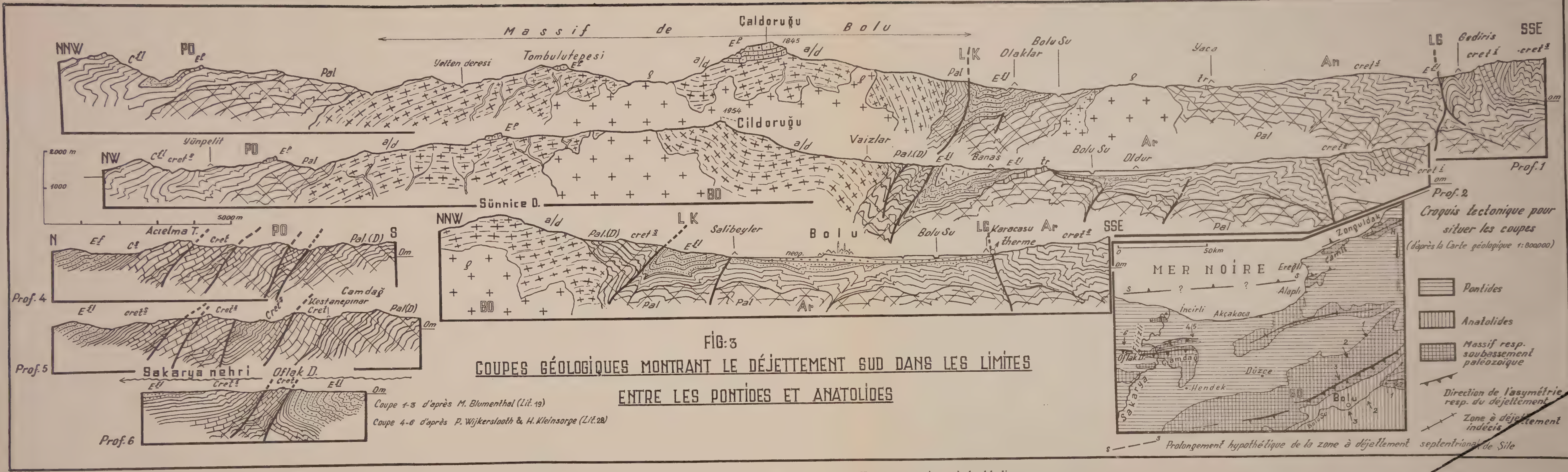


FIG: 3

COUPES GÉOLOGIQUES MONTRANT LE DÉJETTEMENT SUD DANS LES LIMITES ENTRE LES PONTIDES ET ANATOLIDES

Termes tectoniques à double ligne:

An = Anatolides.
Po = Pontides.
Bo = Massif de Bolu.
Ar Massif de l'Arkot Dağ.
LK = Ligne de Karabük.
LG = Ligne de Gerede.

neog = Néogène.
E = Flysch éocène (avec calcaires nummulitiques).
E = Calcaire paléocène.
C = Flysch crétacé.
cret = Crétacé en gébéral.
cret = Crétacé supérieur resp. inférieur.

tr = Trias.
Pal(D) = Paléozoïque en général resp. à Dévonien identifié.
a/d = Schistes cristallins, particulièrement des amphibolites, occasionnellement traversées de diorite.
g = Granite (les points indiquent la diorite).

Kelkit Çay comme obéissant à un chevauchement au Sud (Blumenthal, 1945); et dans la deuxième vallée même le Miocène est engagé sous le flanc du Primaire, étant renversé au Sud [Aluş (Blumenthal, 1948)].

Rebroussons d'ici vers l'Ouest pour faire le parcours dans les Anatolides auxquelles nous avons déjà accedé. Premièrement des noyaux anciens et étendus s'y détachent (noyaux subpontiques et nordégéens (Blumenthal, 1946). De leur côté extérieur, au Nordouest des Dardanelles, les plis de couverture de la nappe tertiaire soulignent fort bien la poussée au N.N.W. [Virgation de Thrace (Paréjas, 1940)]; une asymétrie n'existe presque pas, ce qui également n'a pas pu être reconnu dans les zones sédimentaires entre les rides cristallines du soubassement succédant au Sudest; mais du côté de leur bord intérieur, dans la région de Soma, des écailles vers le Sudest ont été enrégistrées (Kleinsorge, 1941).

Continuant dans les Anatolides, à l'Est nous voulons nous fixer un moment à la coupe transversale de Bolu (Fig. 3). Le Massif ancien de ce nom, qui constitue la haute barrière entre les Pontides et les Anatolides, est suivi de son côté Sud d'accidents tectoniques qui se présentent plus d'une fois comme des chevauchements dirigés au Sudest (L.K. en Fig. 3); au delà de la partie culminante (Prof. 1-3) des plis de couverture du flysch crétacé se succèdent vers le Nord, prenant une allure moins accidentée que le flanc Sud. Se déplaçant de l'extrémité occidental du Massif sur environ 25 km. au Nord et 70 km. plus à l'Ouest on gagne un dispositif tectonique bien déterminé en écailles engageant le Dévonien et sa couverture; c'est la région du Çamdag-Oflak Dağ (Prof. 4–6), située en plein dans les Pontides. Peu au delà, vers le Nord, on peut faire passer hypothétiquement le prolongement du déjettement de la côte bythinienne (S-S en Fig. 3) et, par conséquent, la zone élevée du Primaire de Camli, déjà mentionnée, se place de ce côté. Réunissant l'ensemble à la coupe de Bolu il en ressort un dispositif à déversement opposé qu'on peut faire rapprocher du Cas III mentionné auperavant.

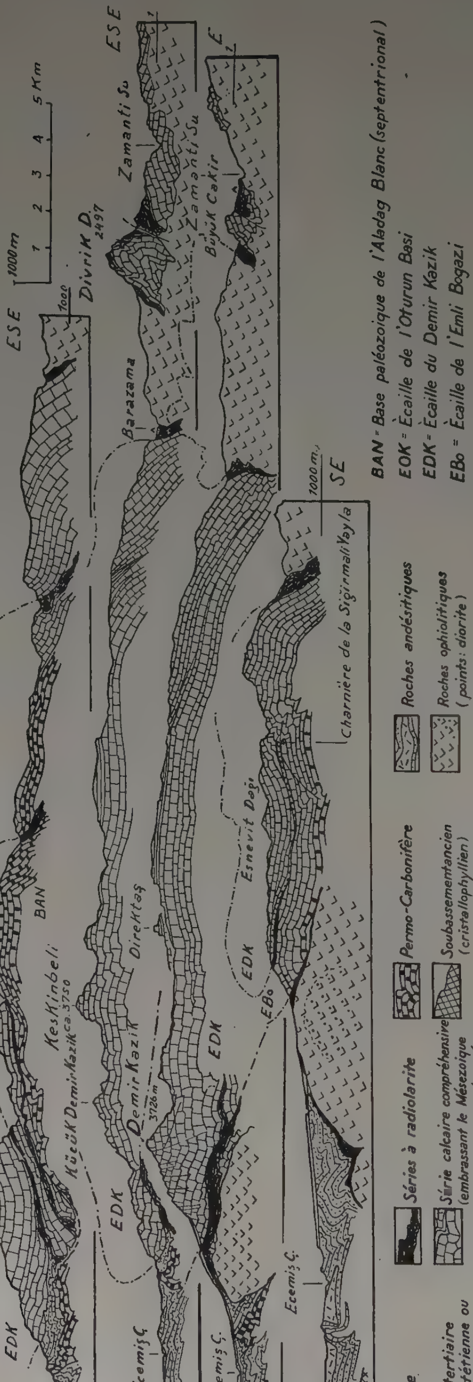
C'est une allure analogue à celle du Massif de Bolu que prend le massif succédant à l'Est, celui de l'Ilgaz Dağ, occupant une zone élevée paléozoïque d'environ 170 km. de longueur (Blumenthal, 1948); son front Sud est plus accidenté que son enfoncement successif au Nord; aux extrémités abaissées à l'Ouest et à l'Est de ce massif les éléments qui le substituent montrent un déjettement variable: à l'Ouest, dans la vallée de l'Ulu Su de Çerkeş, il regarde plutôt le Nord, à l'Est dans l'Inegöl Dağ il fait face plutôt au Sudouest.

C'est en relais, au Sud, que succède plus à l'Est le vaste complexe de formations anciennes rassemblé dans le Massif de Tokat et ses dépendances. Là il s'agit du cas de larges plis de fond (Cas VI) tantôt montrant de déjettement au Nord [Amasya-Zana (Blumenthal, 1950)], tantôt au Sud resp. à l'Est [région entre Tokat et Yildiz-eli (Baykal, 1943; Blumenthal, 1950)]. Une tendance analogue à déborder au Sud se détache sur de longues distances dans le bord intérieur des Anatolides où les éléments structuraux jalonnent la Masse centrale (région Iskilip-Cankiri, région Kalecik-Haymana). Et dans le domaine des grandes rivières de l'Est, de l'Euphrate et de l'Aras où la grande courbure du Taurus estanatolien avance au Nord, il y a même dans le bord de la zone nordanatolienne des charriages dans les éléments de couverture allant au Sud [région de Bingöl: Harrar Dağ-Kigi (Pamir, 1943)]. Au Nordest d'Erzurum, par contre, le déversement se manifeste en charriages allant au Nord-Ouest dans la région du Coruh Nehri (Lahn, 1941).

Ayant avancé dans l'aile septentrionale des Alpides jusqu'à peu près aux extrémités orientales de la Turquie, il découle de notre pérégrination qu'en beaucoup de cas la " Vergenz " est à l'encontre du schéma classique, et que même dans l'aile septentrionale le déjettement au Sud gagne sur celui au Nord. Le parcours du système taurique de l'Asie Mineure, donc de l'aile méridionale nous apprend une inconstance similaire et une opposition analogue au schéma habituel.

Sans faire un arrêt dans les contrées égéennes où une certaine persistance des conditions tectoniques de l'arc hellénique semble se maintenir (Seydlitz, 1931)—la nappe d'Olonos dans la presqu'île de Reşadiye (Philippson, 1915), la courbure du système taurique au Nord d'Antalya attire l'attention. Des nouvelles recherches (Paréjas, 1940) ont montré que les plis lyko-tauriques, rebroussant loin vers le Nord, sont en général, dans leur secteur intérieur, déjettés vers l'intérieur de l'Anatolie et non vers la Méditerranée; il s'y détache comme en Thrace une virgation libre—la Virgation d'Isparta (Paréjas)—

Fig. 4 SÉRIE DE COUPES À TRAVERS L'ALADAG
(Taurus cilicien)
montrant le déjettement opposé de part et d'autre de la zone ophiolitique
(d'après Pl. II, Lit. 17)



qui certainement dépend de l'effet d'un massif profond (promontoire pamphylien) occupant le rentrant d'Antalya. Ce déversement vers l'intérieur se poursuit encore dans l'aile Ouest du Taurus occidental jusqu'aux abords de Seydişehir (Blumenthal, 1947). D'autre part les éléments structuraux, faisant ressortir du côté méditerranéen le rentrant pamphylien, dessinent plutôt une allure indécise [Cas I avec charriages locaux (Altinli, 1945)].

En progressant plus vers le Sudest du Taurus occidental on empiète sur son secteur qui est le plus intensément cisaillé en écailles faisant face à l'extérieur (Sudouest et Sud); la vallée du Manavgat Çay en traverse au moins quatre (Blumenthal, 1951) et par dessus s'étend la Nappe de Hadim engageant dans son corps tout le Paléozoïque fossilifère (Blumenthal, 1944, 1948, 1951). Ce déjettement intense à l'extérieur se maintient certainement jusque dans la courbure Sud du Taurus occidental au delà d'Anamur. Si l'on peut ranger ce secteur du système montagneux dans le Cas IV, le changement brusque à la hauteur de Seydişehir en déversement intérieur, difficilement explicable, corresponderait à des modifications près à la combinaison avec le Type II.

En reprenant la haute chaîne taurique après l'interruption par la couverture néogène (Karaman-Silifke) dans son secteur cilicien, encore un dispositif tectonique bien étrange vient poser un problème. Le déferlement des éléments structuraux à l'extérieur dans l'aile Ouest du grand arc est substitué ici à l'Est par une allure similaire faisant face à l'intérieur de l'Anatolie. Dans la haute chaîne de l'Aladag de complexes importants de la série calcaire mésozoïque sont superposés et ne laissent guère de doute qu'ils ont obéi à un mouvement vers l'Ouest (Fig. 4); la pression active dans ce sens a même eu la force de produire des déjettements dans la zone du Bolkar Dağ, c'est-à-dire dans un élément qui se rattache d'après ses connexions à l'Anatolie intérieure (Masse intermédiaire). L'Aladağ a son pendant au delà d'une large zone ophiolithique dans le Divrik Dağ qui appartient à une zone qui revêt le déversement en direction opposée à celle de l'Aladag (Fig. 4). Il se présente le Cas IV distingué à l'entrée.

Nous ne suivons pas les Taurides plus au Nord-Est; les faits qui se rattachent à notre problème sont encore relativement peu connus et, en plus, les épanchements volcaniques masquent beaucoup la structure sousjacente. Dès le bord oriental de l'Ova d'Adana les Iranides, venant de l'île de Chypre, garnissent une zone située plus à l'intérieur et constituée surtout de roches cristallines. En diverses bandes le déjettement vers l'extérieur de la chaîne se traduit en charriages restreints qui sont ici dirigés contre le bloc arabique; cela s'avère dans les formations mésozoïques (Andirin-Zeytin) et paléozoïques (transversales du Ceyhan et de l'Euphrate) et s'accentue vers l'Est de plus en plus produisant même des charriages du Permo-Carbonifère dans une zone longeant le Tigre à la hauteur de Cizre où les formations anciennes chevauchent le calcaire éocène. Le faîte dorsale est situé plus à l'intérieur et constitue la longue chaîne de Bitlis. On y rencontre le schéma II en tant que de part et d'autre de ce massif paléozoïque les formations mésozoïques montrent un déversement en sens opposé; du côté Sud ce sont des synclinaux pincés ou des nappes limitées qui charrient le " Vorland " tertiaire qui lui-même est cisaillée (Arni, 1939, 1940), tandis qu'au Nord dans le bassin de Van des écailles sont dirigées au Nord-Ouest (Arni, 1939).

Arrivé de nouveau aux frontières orientales de la Turquie, nous coupons court notre analyse rapide et incomplète. Elle a certainement révélé une notable diversité du déjettement dans le sens large du terme dont une bonne partie se base certainement encore sur des observations qui doivent être corroborées par des recherches plus détaillées. Néanmoins l'état actuel de nos connaissances montre qu'il y a une grande inconstance dans le sens du déjettement, à savoir dans la poussée régionale ou locale. Par conséquent, la question se pose de la raison de cette diversité, et spécialement de la conversion, du rejet dans une direction qui n'est pas celle du schéma général.

Il ne peut ici être question d'entrer dans ce thème parce qu'il dépasserait le cadre de cette communication, et l'explication devrait s'appliquer à chaque cas individuellement. Je me borne ici à dire qu'une raison essentielle doit être cherchée dans la grande ampleur qu'acquiert la zone orogénique en Anatolie. Le " peignement " unilatéral des Alpes ne se développait point, de massifs intermédiaires ou de zones élevées du soubassement ancien plus rigides créaient par leur résistance une répartition particulière

des forces en action; le point d'application de la pression maximum et la possibilité d'evasion vers l'espace libre étaient aussi en jeu, ensuite la mobilité relative des sédiments et également l'action des corps magmatiques plus ou moins syntectoniques ont eu une certaine influence. Pour l'Ouest et l'Est de l'aile Sud la dérive des blocs profonds (promontoire pamphylien, bloc syro-arabique) doit être invoquée. Et—*last but not least*—il ne faut pas oublier qu'en maints endroits une différence d'âge entre des plis différemment déversés peut expliquer un dispositif mécaniquement peu compréhensible au premier abord.

Tout ce que je viens d'énumérer ne correspond qu'à des ébauches; leur application pratique serait à la charge des études spéciales.

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THE GEOMORPHOLOGICAL APPROACH TO THE PLEISTOCENE PROBLEM IN BRITAIN

By A. J. BULL

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ABSTRACT

This paper is an attempt to apply the geomorphology of the terraces of the south of England to the elucidation of the sequence of events during the Pleistocene. Recent work has shown that a series of terraces of descending level was cut during the Pleistocene, and in some cases it is possible to place the cold periods in their positions in the terrace sequence. Consideration is given to the low sea-levels that have occurred; and a scheme is suggested for the sequence of events from the time of the cutting of the 200-foot platform to the last glaciation with the accompanying sea-level variation.

THE comparative shortness of the Pleistocene Period and its widely differing sea-levels make it impossible to apply the ordinary stratigraphic methods of geology, which have so readily sorted out the sequences of older formations; nor is it possible to gain detailed information from the fossil contents of the rocks; for, although much valuable work has been done, the time is too short for many changes to have taken place in the forms of animals or plants.

The study of palaeolithic implements has been most informative as to the sequence of the later glaciations, but their variations cannot have the certainty of the fossils of continuously evolving organisms, and unfortunately they have provided no information regarding the earlier glaciations.

The problem of the sequence of events is here considered with regard to the changes in land forms, and while this approach to the problem does not offer a complete solution, it may help in the correct placing of some episodes.

In attempting to apply geomorphological observations to this problem, one must put aside many of the more striking features, because they are the cumulative result of a series of cold periods. Such are the drainage channels of Scotland and the north of England, and the glacial dry valleys and corries in the Chalk hills of the south, which give no indication of the stages of their histories. There are two geomorphological features from which some information may be obtained; they are the evidences of recent low sea-levels and the series of terraces due to variations of sea-level.

J. F. N. Green (1946), in his detailed study of the old river terraces of the Bournemouth district, found that several had horizontal segments in their lowest parts. With the exception of the Muscliff which is deltaic, they are cut in rock and covered with gravel. No doubt each indicates a still-stand of sea-level. These horizontal segments are:—

Ambersham Terrace	190 ft. O.D.
Sleight Terrace	165 ,, ,,
Boyn Hill Terrace	115 ,, ,,
Upper Taplow Terrace	90 ,, ,,
Muscliff Terrace	41 ,, ,,

Other terraces were noted at Bournemouth. They are the Sicilian at about 300 ft. O.D., which was regarded by Henry Bury as a marine planation equivalent to the 100 m. terrace of the Mediterranean; the Upper Ambersham at 250 ft.; the Taplow at 50 ft.; the Staverton coming down to about 45 ft. but going lower; and the Christchurch at 23 ft. O.D.

It is almost certain that the sea-levels that produced these terraces descended with time. King and

Oakley in their study of the Lower Thames Terraces (1936), came to this conclusion, and J. F. N. Green from his studies in Bournemouth and elsewhere, finds no evidence " for a rise of the sea above any of the post-Sicilian terraces " (1946, p. 93).

The conformity of the remants of the Ambersham Terrace (200 ft. platform), (Wooldridge and Bull, 1925, 1928), indicates that no warping nor other movement of the land has taken place since this flat and widespread terrace was eroded in Surrey, Sussex, Dorset, and Devon; and the stability of this part of England no doubt extends to the higher and earlier terraces we are considering (Gossling and Wooldridge, 1926). It may therefore be assumed that the sea has rested successively at the heights indicated.

A recent paper by F. K. Hare (1947) has dealt in great detail with the morphology of the terraces of the Middle Thames, and it is suggestive of probable correlation that he has found six terraces above the Taplow Terrace corresponding to those of Bournemouth. It is of particular interest to note that the fourth terrace up, which had previously been named the Winter Hill Terrace, has much less fall downstream than the others, and this is exactly what one would expect if it is the local equivalent of the very flat Ambersham Terrace.

That the sea has been low in recent times is shown by the drowned valleys and rias round many coasts. Falmouth Harbour is an excellent example; it has received but little sediment, so that the sea fills the main valley and penetrates the lower parts of the tributaries. In Sussex the rias formed by the rising sea have been filled with sediment, and in their lower courses the rivers meander through flats that are nearly horizontal. It has been estimated that during the last glaciation the sea fell 300 feet or more below its present level, while the water was piled on the land as snow and ice. There has doubtless been a number of such oscillations of sea-level; for instance the aggraded or deltaic terrace at Muscliff fills a channel cut in the Staverton Terrace; it follows that after the formation of the Staverton Terrace there was a lower sea-level, presumably caused by a cold period when a channel was cut back into the " Staverton," and then on a subsequent rise of sea-level this was filled with sediment to form the Muscliff Terrace.

In view of the very low sea-level that accompanied the last glaciation it may reasonably be assumed that all the cold episodes, during which ice was piled on the land, were also accompanied by low sea-levels. The drainage from the ice sheets, particularly during the final period of melting, would cut channels, that would later be filled with sediment as the sea-level rose. Two such buried channels are known in our southern rivers. The last two glaciations, which for our purpose may be referred to as the Mousterian and the Magdalenian (Bull, 1942), are represented by the two boulder-clays of Wales deposited by the Irish Sea Ice. Between these two glaciations there must have been a complete melting of the ice in this country, which enabled Aurignacian Man to come north and leave his tools in North Wales. This " oscillation " of sea-level would seem to have resulted in a higher level than the present, for here may be placed the Muscliff Terrace of Green (1946), which fills a channel cut in the Staverton Terrace. On this showing the " Staverton " was the result of the falling sea-level on the oncoming of the Mousterian Glaciation. When, on the melting of the ice, the sea returned to a higher level, the deltaic " Muscliff " was formed. Mr. Green informs me that the palaeoliths found in this terrace are in accord with this hypothesis.

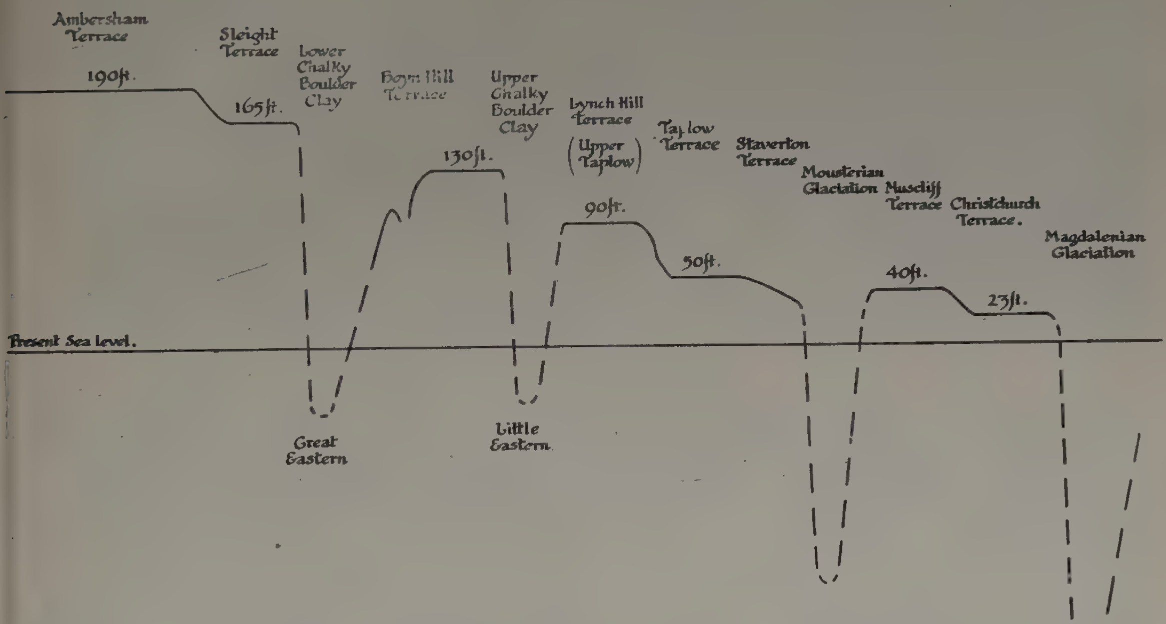
The well known mammalian fauna of the Taplow Terrace gravels indicates cold conditions, which may have heralded the oncoming of the Mousterian Glaciation; if that is so, it would confirm that the cold precedes the lowering of sea-level, and that the cold is not due to the sea going down.

Going back in time the next glaciation of which we have knowledge is that which produced the Upper Chalky Boulder-Clay of East Anglia (Baden-Powell, 1948) (Main Coombe Rock) (Little Eastern). The placing of this glaciation among the terraces is not so certain as the two later ones, but it probably occurred between the Boyn Hill and Lynch Hill Terraces. The name Lynch Hill (Hare) is here being used for the terrace between the Boyn Hill and Taplow Terraces which has been called Upper Taplow (Green), and also Iver. K. P. Oakley has pointed out (Hare, 1947, discussion)

that the Lynch Hill Terrace includes Furze Platt gravel with pointed hand axes of Boyn Hill age and also Iver material containing Levellois flakes. This is here taken to indicate erosion between the formation of these two gravels; the later one (Iver) being an aggradation gravel of Lynch Hill, 90-foot, time; and the low sea-level between the formation of the gravels being that of the " Upper Chalky " cold period.

The varying sea-levels shown in the diagram as occurring during the Boyn Hill inter-glacial are founded on those indicated by King and Oakley (1936), and they are terminated by a rise to about 130 ft. O.D., when the striking terraces of the Arun Gap, Sussex, were shaped (Bull, 1932) and the gravels of Dartford Heath and the Goodwood beaches were accumulated. The erosion by which this period is shown to be interrupted has been the subject of much discussion.

The Great Eastern Glaciation is more easily placed in the series of terraces. Its ice sheet produced the Lower Chalky Boulder-Clay, which was deposited on the Ambersham Terrace and also in the little valleys that had been cut in it (Wooldridge, 1928). It therefore followed the planing of the " Ambersham," not immediately, but after some further denudation had taken place, and so it may be placed between the Sleight and Boyn Hill Terraces. This would agree with the Wimbledon Common—



This graph is an attempt to indicate what may have been the variations of sea-level with time during the later part of the Pleistocene. No attempt is of course made to suggest the relative lengths of the periods.

The horizontal line at 190 feet O.D. represents the long still-stand during which the remarkably flat Ambersham Terrace was eroded. The next lower terrace, the Sleight, was of shorter duration, and this was followed by the Great Eastern Glaciation which produced the Lower Chalky Boulder-Clay, and which it is assumed was accompanied by a low sea-level.

When warm conditions were resumed, the still rising sea-level produced the aggradation deposits of the Boyn Hill Terrace, and these culminated in the Dartford Heath Gravel and the cutting of flats in the South Downs rias of the time. A mid-Boyn Hill erosion is indicated.

The cold that produced the Upper Chalky Boulder-Clay is provisionally placed next, although it may be later. This is followed by the Lynch Hill (Upper Taplow) and Taplow Terraces, while the Staverton Terrace is presumably due to the falling sea-level of the Mousterian Glaciation. The next terrace is the deltaic " Muscliff " indicating the return of warmth and a higher sea-level than the present. Then followed the " Christchurch " and doubtless a number of lower terraces as the sea went down to the very low level from which it has only recently recovered.

Kingston flat being of " Sleight " age and having upon it an outwash gravel with Midland erratics brought by the ice sheet.

The Ambersham Terrace consists of widely scattered and often small remnants of a very flat but uncompleted peneplain. It was first noted in the gap in the North Downs through which flows the River Mole (Wooldridge and Bull, 1925). It was then traced up that river and through the London Basin (Wooldridge, 1928), along the fringe of the South Downs into West Sussex (Kirkaldy and Bull, 1940), and into Dorset and Devon. The deposits on it are in Essex the Lower Chalky Boulder-Clay and in Sussex a sand with sharp angular flints.

The scheme outlined above is an attempt to bring the later glacial episodes into their places in the succession of terraces and hence sea-levels that have now been established. It is here assumed that the Ambersham Terrace is one of the episodes of the Pleistocene and not of a much earlier date. If this is so, then at least one glaciation preceded it, and it must represent by far the longest of the inter-glacials. These earlier glaciations are not so readily placed among the morphological features, and no attempt to do so is made here.

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DISCUSSION

A. J. Pannekoek said that he would like some information on two points. In the first place Dr. Bull had mentioned the great flatness of the 200-foot platform. This flatness was rather astonishing if the natural slope of the rivers was taken into account, unless all the present occurrences of the platform had originally been near the base level.

The second point was the fact, stressed both by Dr. Bull and by Dr. Sprigg in another paper, that the younger sea-levels were always lower than the older ones, which fact could not be explained by the Milankovitch diagram. There must be another cause superposed on it.

A. J. Bull replied that he had perhaps over-emphasized the flatness; the platform was so much flatter than the river terraces. As to its height, in the Mole Gap it was 205 feet above sea-level; in Sussex down to 195 feet where it approached the river gaps; but as expected, against the higher ground of the central Weald it rose to perhaps 230 feet. It had not been traced above 240 feet. In the middle Thames it rose to about 260 feet. As to the dip it was not possible to say anything definite.

R. C. Sprigg said that one had to admit that there were still many puzzling features in relation to the theory of the over-all continuously declining sea-level of the Pleistocene (and the late Tertiary). Evidence from many parts of the world did, however, support such a view. Progressively younger stranded sea beaches occurred at successively lower altitudes along many relatively stable coasts.

The cause of that negative eustatic movement was unknown. Several theories had been advanced and the one most frequently cited involved the progressive deepening of one or more ocean basins. The evidence for that theory was very indirect and inconclusive.

Dr. Sprigg pointed out that when one accepted the fact of a declining sea-level, there still remained the problem as to how smoothly it had occurred. Was it a jerky fall, did it occur more rapidly at some times than at others, or was one justified in assuming a sensibly straight line relation with the passage of time? A graph prepared by Prof. Zeuner suggested the latter.

F. E. Zeuner referred to the Ambersham Terrace, and said that there was a much higher level in the London basin dated as Diestian. That was clearly marine. There were fossils in one or two places, and also cliffs. There the sea-level

was determinable. It was about 650 feet all round the London basin. It bore out Dr. Bull's conclusion that there was no recent large scale tectonic movement in the south of England. The Ambersham levelling was no evidence of sea action. There the whole river system of the country approached a base level. The sea-level might have been at 200 feet or even lower, as Dr. Bull had pointed out. It corresponded well to the 56 metre level of the Mediterranean (the Milazzian), and along the coasts of the North Atlantic which probably represented the first interglacial.

The speaker said that with regard to the continued drop of sea-level in the Pleistocene, Dr. Bull's evidence could be accepted as fact; there had never been evidence of later sea-levels transgressing earlier ones. Another factor was solar radiation. If the sea-levels of successive interglacials were plotted against time, they fell exactly on a straight line—a good argument in favour of the Milankovitch curve. Lastly, he referred to the remarkable work of Baulig, who had recognized a continuous drop through the latter half of the Tertiary, and ascribed it to gradual movements of the floor in the ocean basins.

LES FOSSES QUATERNAIRES D'EFFONDREMENT DE TUNISIE

Par G. CASTANY

Tunisia

RÉSUMÉ

Les études géologiques confirmées par des recherches géophysiques et des sondages hydrauliques profonds ont mis en évidence la présence, en Tunisie, d'importantes fosses d'effrondrement. Les plus connues sont celles du Lac de Tunis, de Grombalia, Kairouan, Kasserine et du Djérid.

Les plaines de Grombalia et de Kairouan apparaissent comme de véritables " graben " comblés de terrains récents. La structure des bordures fait apparaître de nombreuses flexures et failles tronquant les plis. Les sondages profonds ont recoupé, au centre, des puissances notables de sédiments: plus de 400 mètres de Quaternaire marin à Grombalia et 500 mètres de Plio-Quaternaire continental à Kairouan-Kasserine.

La rive septentrionale du Chott Djérid montre, au-dessus du Pontien plissé, des couches à *Cardium édule* affectées de pendages Sud de 15° et plus. La cuvette du Chott apparait ainsi comme une zone affaissée. Le sondage de Rherdgaïa est venu confirmer cette hypothèse.

Ces accidents traduisent l'influence de mouvements pliocènes de subsidence qui se sont poursuivis au cours du Quaternaire et dus à une phase d'ajustement isostatique.

De nombreuses études géologiques confirmées par des recherches géophysiques et des sondages hydrauliques ont mis en évidence, en Tunisie, la présence d'importantes fosses d'effondrement.

H. Schoeller, étudiant en 1939 le Quaternaire de la plaine de Grombalia, au Sud-Est de Tunis, y montrait l'existence d'un fossé subsident profond. Il signalait, en outre, des structures analogues au Mornag et dans les vastes cuvettes synclinales de la Tunisie Centrale.

Ces observations furent précisées plus récemment par J. Archambault (1947) dans un ouvrage consacré à l'Hydrogéologie Tunisienne pour les régions de Kairouan, Oued Guéniche, Mabtouha et Golfe de Tunis.

Nous nous proposons, dans cette note, d'exposer en les coordonnant nos connaissances actuelles sur ces unités structurales.

L'Atlas Saharien est affecté en Tunisie de nombreux accidents qui, soit transversaux, soit internes aux plis, ont donné naissance à des effondrements. L'importance des travaux de recherches hydrauliques mis en oeuvre ces dernières années a permis d'identifier avec certitude une certain nombre d'entre eux. Nous citerons la Garet Ichkeul-Oued Guéniche, le Lac de Tunis, les plaines du Mornag, de Grombalia, de Kairouan, du Lac Kelbia, de la Sebkra Sidi El Hani, de Kasserine, de Sidi Bou Zid, de Sbiba-Siliana et du Djérid. D'autres, probables, sont décelés par le Géologie, à Madjen Sidi Abbès, à l'Oglet Methnène (Est de Maknassy-Mezzouna) et dans la Haute et Basse vallée de la Medjerda.

Nous exposerons en détail l'étude des plus typiques:—

(1) Golfe de Tunis;
(2) Plaine de Grombalia;
(3) Cuvette de Kairouan;
(4) Plaine de Kasserine;
(5) Chott Djérid;
(6) Cuvette de Sidi-Bou Zid.

I. GOLFE DE TUNIS

La ville de Tunis est dominée à l'Ouest par des collines qui sont constituées, au Sud de terrains éocènes et au Nord de grès et d'argiles à *Helix* du Pliocène. Les affleurements accidentés de nombreuses

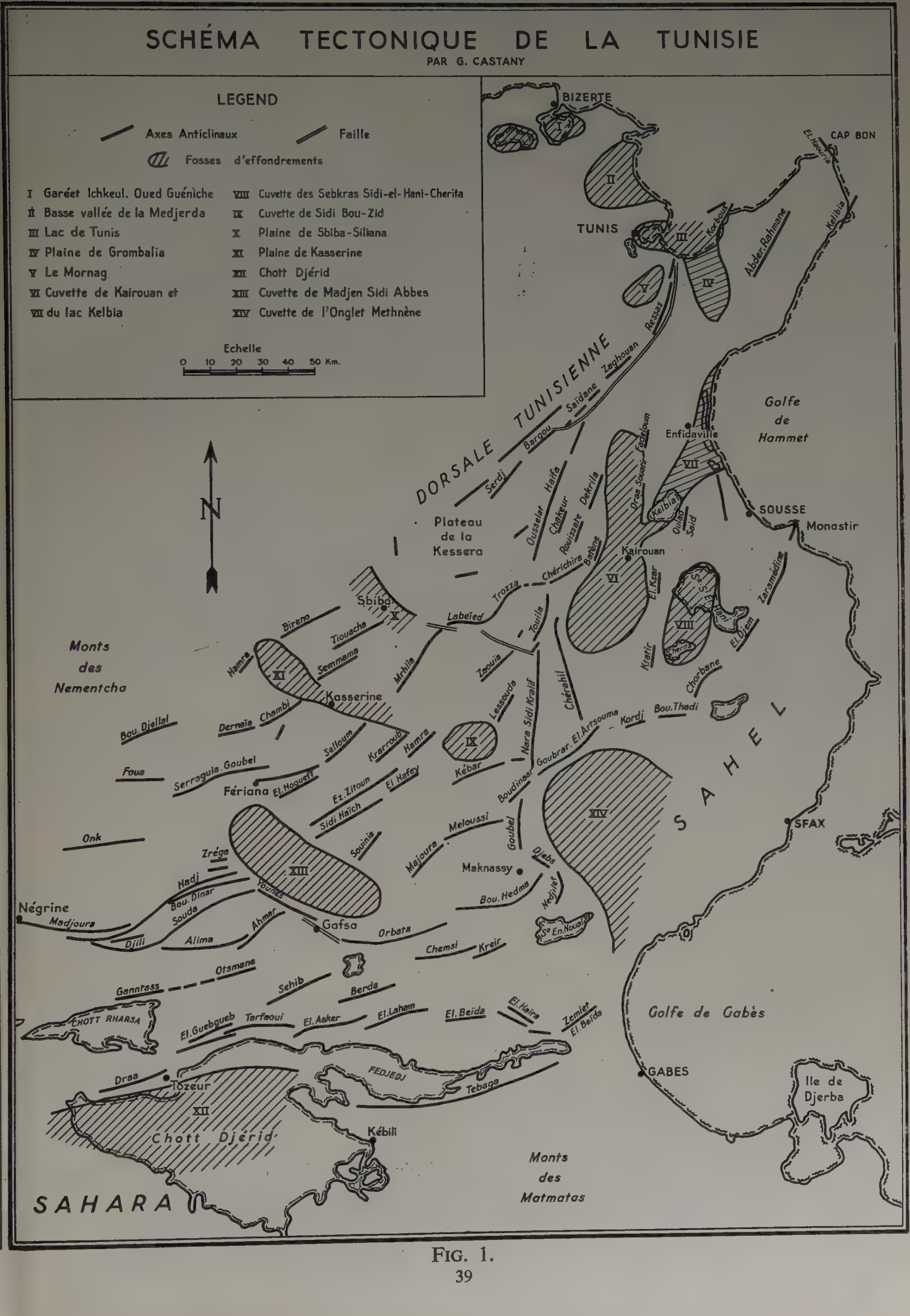
SCHÉMA TECTONIQUE DE LA TUNISIE
PAR G. CASTANY
LEGEND
Axes Anticlinaux
Faille
Fosses d'effondrements
I Garéet Ichkeul. Oued Guéniche
II Basse vallée de la Medjerda
III Lac de Tunis
IV Plaine de Grombalia
V Le Mornag
VI Cuvette de Kairouan et
VII du lac Kelbia
VIII Cuvette des Sebkras Sidi-el-Hani-Cherita
IX Cuvette de Sidi Bou-Zid
X Plaine de Sbiba-Siliana
XI Plaine de Kasserine
XII Chott Djérid
XIII Cuvette de Madjen Sidi Abbes
XIV Cuvette de l'Onglet Methnène
Echelle
0 10 20 30 40 50 Km.
BIZERTE
CAP BON
TUNIS
DORSALE TUNISIENNE
Plateau de la Kessera
Enfidaville
Golfe de Hammet
SOUSSE
Monastir
Kairouan
Sbiba
Kasserine
Monts des Nementcha
Fériana
SAHEL
SFAX
Maknassy
Négrine
Gafsa
CHOTT RHARSA
Golfe de Gabès
GABES
Ile de Djerba
Tozeur
Chott Djérid
Kébili
Monts des Matmatas
SAHARA
FEDJEDJ
Tebaga
Kelibia
Abder-Rahmane
Korbous
Ressas
Zaghouan
Saïdane
Bargou
Serdj
Ousselat
Haïfa
Chakeur
Rouissate
Dekrila
Batène
Chérichira
Trozza
Labeïed
Bireno
Tiouacha
Semmama
Hamra
Chambi
Derneïa
Bou. Djellal
Foua
Serraguia. Goubel
Selloum
Krarroub
Mrhila
Zaouia
Touila
Lessouda
Nara Sidi Kralif
Chérahil
Kébar
El Hafey
Ez. Zitoun
Sidi Haïch
Souinia
Onk
Zréga
Hadj
Bou. Dinar
Souda
Madjoura
Djili
Alima
Ahmar
Younès
Orbata
Chemsi
Kreir
Bou. Hedma
Medjilet
Djebs
Goubel
Meloussi
Majoura
Boudinar
Goubrar. El Artsouma
Kordj
Bou. Thadi
Chorbane
Ktatir
El Kser
El Djem
Zaramédine
Oulad Saïd
Fadeloum
Draa Souatir
El. Haouria
Ganntass
Otsmane
Sehib
Berda
El. Guebgueb
Tarfaoui
El. Asker
El. Laham
El. Beïda
El. Haïra
Zemlet
Draa

FIG. 1.

cassures laissaient prévoir, en bordure, des accidents importants qui ont été reconnus par des sondages profonds. Dans la Banlieue Nord la butte du Belvédère, à la cote 82, fait affleurer du Pliocène. Un sondage implanté à 800 mètres à l'Est dans la plaine des Cités Jardins (Cote 10) a recoupé cet étage vers 200 m. de profondeur. Plus au Sud, rue Kléber, un forage de recherches de gaz exécuté en 1940–41 a rencontré de 0 à 360 mètres des couches dont la microfaune étudiée par E. Dumon et J. Archambault est certainement quaternaire. Vers 363 m. il a retrouvé les marnes grises et brunes à *Helix* du Belvédère.

Plus au Sud-Est les sondages de Djebel Djelloud ont traversé 145 et 160 mètres de Quaternaire avant d'atteindre les calcaires éocènes connus en affleurements 300 mètres à l'Ouest.

Nous sommes donc en présence d'une faille post-pliocène sensiblement méridienne qui a provoqué l'affaissement du compartiment oriental, le golfe de Tunis.

Le récent tremblement de terre de mai 1948 localisé selon une ligne Nord-Sud de Porto Farina à Klédia et dont l'épicentre se situe à 3 km. sous la capitale de la Régence est vraisemblablement une manifestation actuelle de cette importante fracture du socle profond.

Il est intéressant de noter que cette région instable correspond à la terminaison septentrionale d'une des zones tectoniques la plus accidentée de Tunisie, la Dorsale Tunisienne.

Plus à l'Est ces mouvements sont en relations avec la troncature du Bou Kornine, vers Hammam-Lif (Sources thermales).

II. PLAINE DE GROMBALIA

Les plis S.W.–N.E. de la région du Cap Bon sont séparés de la Dorsale Tunisienne par une cuvette orientée S.E.–N.W. comblée de sédiments quaternaires. À l'Ouest les accidents de la Dorsale marquent un rebroussement vers le Nord pour prendre une direction méridienne, avec formation d'écailles dans la zone du Djebel Makki, de telle sorte qu'à l'Est les dômes S.W.–N.E. du Cap Bon n'en sont pas le prolongement. La plaine de Grombalia sépare donc deux régions tectoniques nettement distinctes.

La géologie de surface étudiée en détail par H. Schoeller (1939) constitue une synthèse remarquable des étages quaternaires. Des recherches de prospection électrique entreprises en 1932 par la Compagnie Générale de Géophysique, avaient mis en évidence dans le centre de la cuvette l'accumulation de dépôts sur plus de 1.000 mètres avec à la base de la série un terrain très conducteur (1 ohm m2/m.). Les bords paraissaient liés à d'importantes flexures passant à des fractures.

À la suite de ces travaux, dès 1935, une campagne de sondages profonds de recherches hydrauliques fut entreprise par la Direction des Travaux Publics. Les résultats ont été concluants.

(*a*) *Sondage de Soliman.*—Foré en 1935 à 400 mètres au Nord de Soliman (cote 11) il a atteint la profondeur de 310 mètres. Les couches traversées sont toutes attribuables au *Quaternaire marin*. En particulier une très belle faune rencontrée entre 256 m., 70 et 259 m., 70 décrite par H. Schoeller (1939, p. 11) ne représentant que des espèces actuelles est essentiellement quaternaire.

(*b*) *Sondage de l'Oued Bézirk.*—Au Nord de la plaine un forage a reconnu sur 126 mètres du *quaternaire marin* bien identifié avec un faciès littoral.

(*c*) *Sondage de Grombalia-Beni Khalled.*—En 1942 on décida d'implanter au Centre même de la cuvette, à 7 kilomètres au Nord-Est de Grombalia, un sondage profond (cote 36). Poussé jusqu'à 430 mètres il n'a recoupé que des terrains quaternaires avec de nombreux niveaux fossilifères. On peut distinguer dans la coupe:

de 0 à 54 m., 50 un *Quaternaire continental* formé d'alternances de sables argileux et de marnes plus ou moins sableuses;

de 54 m., 50 à 130 m. un *Quaternaire marin littoral* essentiellement sableux avec de nombreux lits de fossiles où le *Cardium édule* L. domine;

de 130 m. à 430 m. un *Quaternaire lagunaire* marneux à couches de gypse et de sel et un niveau de sel massif (384 m. à 393 m.).

Cette coupe montre la présence sous le Quaternaire continental de couches quaternaires marines et lagunaires avec des bancs de gypse et de sel, phénomène prévu par la Géophysique.

Ainsi le Quaternaire marin ou lagunaire reconnu par sondages a été rencontré aux cotes, négatives par rapport au niveau de la mer, de 299 à Soliman, 111 à l'0. Bézirk et 394 à Grombalia.

Le Sicilien daté aux terrasses orientales de 110–150 mètres se situerait donc, à 15 kilomètres plus au Nord, à plus de 400 mètres de profondeur. Or, comme le fait judicieusement remarquer H. Schoeller la faune de Soliman, plus septentrionale, rencontrée à -257 m. comprend des espèces qui ne peuvent vivre au-dessous de 60–70 mètres et même pour certaines au-dessous de 20 mètres. On ne peut admettre qu'elles aient été transportées au fond d'une fosse sous-marine par des courants, hypothèse en contradiction avec la présence sous Grombalia de formations lagunaires (sel gemme et gypse). Par contre tenant compte d'observations et de cas semblables en d'autres points de la Régence il est plus logique d'admettre que depuis le Quaternaire ancien et les temps anté-siciliens le soubassement de la plaine a subi un affaissement de plus de 500 mètres.

Les dépôts reconnus comme siciliens ou plus récents peuvent donc se situer à différentes cotes et par conséquent se baser ici sur les altitudes des terrasses pour établir une chronologie du Quaternaire parait délicat et peut conduire à des erreurs.

Ainsi, si le Quaternaire marin de la plaine de Grombalia montre un bel exemple de régressions marines successives, il nous est difficile d'attribuer un âge à ces mouvements qui semblent être conditionnés davantage par les fluctuations tectoniques locales dues à l'affaissement progressif du substratum que par un phénomène eustatique général.

Toutes les recherches entreprises: géophysique, sondages profonds nous conduisent à la même conclusion: la plaine de Grombalia est un fossé d'effondrement, véritable " graben." La géologie complexe et les structures fracturées des bordures Ouest et Sud-Est sont en relation étroite avec cet affaissement considérable dont nous ne connaissons pas encore toute l'ampleur. Les puits forés montrent un ennoyage rapide des couches en relation avec des flexures et des failles.

Nous devons, en outre, signaler que des levers récents exécutés au Sud-Est, vers Nabeul, par MM. Amira et Muller-Feuga, géologues au Service Géologique, ont mis en évidence un Pliocène très puissant, accidenté de fractures parallèles, orientées N.W.–S.E. (c'est à dire selon le grand axe de la fosse de Grombalia) dont les rejets sont de l'ordre d'une centaine de mètres. Ces accidents prouvent l'existence d'une phase tectonique post-pliocène importante.

Quel est l'âge de cet affaissement? Nous avons montré que les couches quaternaires même les plus récentes ont été affectées par le mouvement de subsidence qui doit d'ailleurs se perpétuer actuellement. Dans le passé il est difficile de fixer avec précision l'origine de ces déformations. L'étude détaillée des bordures nous porte à croire que le fossé de Grombalia était déjà esquissé au Miocène avant l'orogénèse alpine.

Il est certain toutefois que les failles et flexures datant le paroxysme du mouvement sont post-pliocènes.

La plaine de Grombalia est ainsi un fossé d'effondrement post-pliocène dont les déformations et la subsidence se sont poursuivies au cours des temps quaternaires.

III. CUVETTE DE KAIROUAN

Les plis du Sahel sont séparés des accidents de bordure par une vaste plaine quaternaire: la cuvette de Kairouan. S'étendant, du Nord au Sud, sur plus de 100 kilomètres, et une largeur maximum de 35, elle est limitée à l'Ouest par les plis périsahéliens Avant-Monts de la Dorsale Tunisienne. De Djebibina à Bir El Aouani les accidents orientés S.S.W.–N.N.E. sont interrompus par la plaine selon une ligne méridienne et, ainsi que l'ont montré les sondages, ne se poursuivent pas sous les atterissements récents. De Bir El Aouani à El Aouareb, les Djebels Batène et Chérichira, de structure complexe sont les témoins des efforts orogéniques intenses dont cette région fût le théâtre. La terminaison septentrionale du Batène est tronquée par une fracture, alors que le pli-faille du Chérichira fait apparaître du Trias intrusif. À la bordure orientale, la plaine de Djebibina est limitée par les dômes crétacés et tertiaires des Djebels Garci, Fadeloum et Hassine; la région d'El Alem par la faille N.–S. du Draa Es Souatir. Vers le Sud les reliefs sont moins accusés et uniquement constitués de terrains pliocènes et quaternaires.

L'étude stratigraphique de ces plis appelle une remarque importante au sujet du Pliocène. Cet

étage bien représenté sur le flanc oriental du Djebel Batène et au Chérichira affecte des pendages de 30, 40 et même 50 degrés. Les plissements dans cette région se sont donc poursuivis au-delà du Pontien et on doit reconnaître l'existence d'une phase orogénique post-pliocène.

Les structures complexes de bordure, laissaient prévoir un affaissement de la plaine, hypothèse controlée par les sondages profonds entrepris depuis 1942 par la Direction des Travaux Publics, en vue de la mise en valeur hydraulique de ces régions.

Tous les forages, même ceux voisins de affleurements n'ont recoupé que des alternances de sable plus ou moins grossiers, de galets, de marnes et d'argiles rouges ou jaunes que la comparaison avec les gisements de surface révèle post-pontiennes. Ce sont des couches continentales que l'on doit attribuer pour la plus grande partie au Quaternaire. La base représenterait dans plusieurs coupes le Pliocène continental. Les profondeurs respectivement atteintes sont de 201 m. à Henchir Gallèle, 300 à El Haria, 358 à Bir Zeddame, 323, 391 et 536 à l'Ouest de Kairouan, 315 à l'Oued Zafrane.

La cuvette de Kairouan est une fosse de subsidence de direction méridienne, se raccordant à ses bordures par des failles. L'accumulation sur de grandes épaisseurs de sédiments continentaux, identiques du point de vue lithologique, certainement post-miocènes, plio-quaternaires implique un phénomène de subsidence qui commencé dès le Pliocène s'est poursuivi durant le Quaternaire et n'a vraisemblablement pas cessé de nos jours.

C'est là une nouvelle preuve de l'existence en Tunisie de déformations tectoniques importantes au cours des périodes Pliocène et Quaternaire.

IV. PLAINE DE KASSERINE

Les plis issus de la frontière algéro-tunisienne dans la région de Fériana sont brusquement interrompus au Sud de Kasserine par un grand accident transversal N.W.–S.E., long de plus de 50 kilomètres, qui a donné naissance au Nord à la plaine quaternaire de la Foussana-Kasserine.

Déjà décrite par L. Pervinquière (1903 pp. 51, 53, 80, 97, 115 et 118), puis par E. Berkaloff et dernièrement par Roumiguières et Uguet (1946) la géologie en est bien connue.

Les axes anticlinaux et synclinaux quoiqu'interrompus, se prolongent de part et d'autre de cet accident. Ce sont successivement d'Ouest en Est:

- anticlinal de Rhourfet er Rhoumia;
- synclinal du Bahiret El Oubira;
- anticlinal du Djebel el Hamra;
- synclinal du Bou Driés Bled Zelfane;
- anticlinal Chambi-Semmama;
- synclinal Kasserine-Garat El Atech;
- anticlinal Selloum-Maargaba.

Ces plis sont coupés par une série de fractures dont la résultante est orienté N.W.-S.E. Cette ligne générale délimitant les plaines de la Foussana et de Kasserine représente la direction moyenne d'une série de failles en zig-zag analogues à celles que l'on observe sur la bordure et les flancs des Djebels crétacés. Certaines d'entre elles comme celle du goulet de Sidi Laaba affectent les couches pliocènes redressées à la verticale. Elles coïncident avec l'apparition de Trias diapir aux Chambi et El Hamra, et à une sérélevation d'axe des anticlinaux. La perturbation apparait plus intense au Chambi, puis au Selloum et enfin au El Hamra. Ces failles affectant les plis post-pontiens sont ainsi postérieures à ces derniers. Le paroxysme des accidents transversaux est donc post-alpin. La complexité structurale des bordures et la présence de la faille dite " de la falaise de Kasserine " permettaient de supposer l'effondrement de la plaine quaternaire septentrionale, que des sondages hydrauliques profonds ont permis de mettre en évidence.

Sondages de Kasserine

Sondage No. 4.—Foré en 1942 à 200 mètres à peine des affleurements aptiens du Chambi il a recoupé 33 mètres de terrains continentaux récents appartenant au Quaternaire continental, remplissage du Goulet de l'Oued Hatob.

Sondage No. 2.—Implanté à 1,200 mètres au Nord de la falaise dans les alluvions de l'Oued il a recoupé sur toute sa hauteur, soit 300 mètres, les alternances d'argiles avec galets et de sables plus ou moins argileux horizontaux du Quaternaire continental.

Sondage de la Foussana

Un puits foré au centre de la cuvette de la Foussana a rencontré 300 mètres de Quaternaire continental.

La plaine de Kasserine est donc une fosse d'effondrement post-pliocène comblée de sédiments continentaux.

V. CHOTT DJÉRID

Des études récentes dans la région du Djérid ont permis de préciser certains points géologiques. Au dessus de couches à gypse et conglomérats plissés du Pliocène, la série se termine par un niveau quaternaire à *Cardium édule* L. En de nombreux points sur le flanc méridional du Draa, en bordure du Chott Djérid cet horizon présente des pendages vers le Sud, 10° à Helba et 15° entre Degache et Zorgane. Nous en avions conclu à la présence d'un fossé d'effondrement sous le Chott. À la suite des études géologiques un grand sondage de recherche d'eau fut entrepris à mi-chemin entre Nefta et Tozeur. Poussé à plus de 500 m. dans le Miocène supérieur il a mis en évidence l'accentuation des pendages en profondeur, qui de 40° en surface paraissent atteindre la verticale. Ces résultats confirment notre hypothèse. La cuvette de Chott Djérid est un fossé de subsidence récente.

VI. CUVETTE DE SIDI BOU ZID

En plein coeur de la Tunisie Centrale entre le plis N.–S. de la bordure du Sahel (Sidi Kralif) et les dômes S.W.–N.E., se situe une vaste dépression quaternaire, la cuvette de Sidi Bou Zid. C'est une zone d'alluvionnement intense. Depuis la construction de la route Sbeïtla-le Faïd le niveau s'est élevé de 1 à 2 mètres. Des sondages forés au centre, ont recoupé des formations continentales plio-quaternaires sur 320 m. au puits No. 1 et 300 au puits No. 2.

Quoique les études ne soient pas achevées il est possible de prévoir des structures identiques en différents points de la Tunisie.

Les dépressions des Gareets Ichkeul, lac de Bizerte et Oued Gueniche au Nord de la Tunisie sont marquées par leurs accidents de bordure, faille de l'Ichkeul (sources thermales, métamorphisme) et le sondage de l'Oued Gueniche à l'extrémité orientale.

La Haute Vallée de la Medjerda de Ghardimaou à Souk El Khémis montre des bordures très accidentées avec pliocène plissé jusqu'à la verticale, une zone métamorphique à l'Haïrech et d'énormes accumulations de sédiments récents.

Il en est de même dans la basse vallée.

Dans la plaine du Mornag au Sud-Est de Tunis, le sondage des Nassen No. 1 a recoupé 190 m. de terrains récents et celui de la ferme de Sidi Saad, 200 m.

La plaine Est-Ouest de Pont du Fays à El Aroussa manifeste elle aussi des phénomènes de subsidence.

Au Sud-Est de Pavillier, le sondage de l'Aïn Soltane recoupant 185 m. de plio-quaternaire indique la présence, sur l'emplacement de la Sebkra El Hani d'un deuxième accident comparable et parallèle à celui de Kairouan.

Plus au Sud c'est le forage de la cuvette de l'Oglet Methnène qui a recoupé 100 m. de terrains post-pontiens.

CONCLUSIONS

La présence de fossés d'effondrement est un phénomène remarquable en Tunisie par son ampleur et sa généralité. Toutes les unités que nous avons décrites, comblées de terrains plio-quaternaires sont les témoins d'un cas de subsidence récente qui se poursuit vraisemblablement de nos jours.

Les unes comme le lac de Tunis et la plaine de Grombalia sont largement ouvertes vers la mer, les autres dont le type est réalisé à Kairouan complètement fermées.

L'étude de ces accidents met en évidence la présence de mouvements tectoniques importants post-pliocènes, déformations qui se sont poursuivies au cours du Quaternaire. Ce dernier est déformé en bordure du Djérid et affaissé dans les " graben " de Grombalia, Kairouan et Kasserine.

Ces faits ne sont pas limités à la Tunisie. L. Glangeaud avait montré dès 1927 le rôle de la phase tectonique post-astienne dans la structure et la morphologie de l'Atlas littoral algérien. R. Laffitte (1942) a indiqué dans le Sud de l'Aurés du Pliocène plissé avec pendages de 30, 45 et même 60 degrés. Ces observations mettent ainsi en évidence la présence d'une phase tectonique post-pliocène et anté-quaternaire que L. Glangeaud précise dans la Mitidja comme étant post-astienne.

Des déformations quaternaires ont déjà été signalées par Roux en 1911 dans la chaîne de Moularés-Négrine où l'on observe des cailloutis d'âge paléolithique déformés à Sidi Bou Diaf et au Djebel Blidji (Oued Zoubia) Vaufrey les a notées également aux environs de Gafsa en 1934. Plus récemment R. Laffitte (1942), a décrit des mouvements récents post-Tyrrhéniens en Algérie occidentale.

En Algérie comme en Tunisie ces déformations tardives à grand rayon de courbure se reliant aux bordures par des flexures et délimitant de vastes régions naturelles jouent un rôle important dans la topographie actuelle.

Il est vraisemblablement que nous nous trouvons en présence d'un phénomène analogue à ce que L. Glangeaud a nommé, dans le Jura, la phase d'ajustement isostatique post-tectonique.

Le socle a joué ici un rôle directeur dominant. Ses distensions, ses fractures, sont la cause des effondrements observés. Hypothèse qui se trouve corroborée par le récent tremblement de terre de Tunis et la zone instable de Gafsa. À son propre jeu se sont ajoutés les mouvements de couverture; plissement, disharmonie.

La permanence des déformations du bâti profond au cours du Secondaire et du Tertiaire, montrées clairement par les études géologiques récentes, a abouti logiquement dans une phase finale de l'Orogénèse à l'ajustement isostatique des régions ainsi différenciées.

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TECTONIQUE DU PORTUGAL

Par J. CARRINGTON DA COSTA

Portugal

RÉSUMÉ

On fait la synthèse et la critique détaillées de toutes les connaissances relatives à l'orogénie et aux manifestations magmatiques du Portugal métropolitain.

On note les témoignages des actuations huroniennes mais on ignore à peu près les caractéristiques de leur chaîne au Portugal.

On montre l'importance des mouvements calédoniens qui ont determiné l'émersion, au Nord, du bloc calédonique, lequel a eu un important rôle durant l'activité hercynienne.

On met en relief l'importance extraordinaire des mouvements hercyniens, car, faisant émerger, au Sud, le bloc hercynique, ils ont déterminé la constitution du grand Massif Hespérique, véritable ossature de la Péninsule Ibérique, lequel a été troublé aussi, postérieurement, par plusieurs phases des mouvements alpins, les unes ayant délimité, les autres ayant rajeuni son relief. On fait l'étude détaillée de tels effets.

On montre que presque toutes ces activités ont été accompagnées par des genèses de roches éruptives de plusieurs types, lesquelles seront indiquées, non seulement en ce qui concerne leurs caractéristiques, mais aussi en ce qui a trait à leur distribution dans l'espace et dans le temps.

Finalement, on fait référence à l'évolution de la ligne de la côte, aux terrasses fluviatiles et marines, et à la glaciation pendant le Quaternaire, montrant la corrélation de ces divers phénomènes.

BEAUCOUP de recherches géologiques dernièrement faites au Portugal fournissent des éléments de valeur pour l'étude de sa tectonique. Il est donc possible de faire une revision des divers problèmes et d'essayer une synthèse critique sous un nouveau jour.

Toutefois, cette dernière ne peut être présentée dans tous ses détails en raison des restrictions d'espace et de temps. Par contre, il y a toute convenance à indiquer les principales caractéristiques de la tectonique du Portugal qui peuvent intéresser des études ultérieures, notamment celles d'ensemble, qui embrassent des aires plus étendues. Nous allons donc brièvement les mettre en évidence, sans préoccupations d'ordre théorique, spécialement en ce qui concerne les hypothèses tectogéniques.

Il y a longtemps qu'on reconnaît l'existence de certaines unités structurales, fondamentales, mais on ne doit pas oublier que le Portugal présente des frontières politiques, et que diverses formations géologiques se prolongent jusqu'en Espagne. Celles-ci appartiennent au Massif Hespérique (Méseta Ibérique), qui constitue le grand noyau central et basilaire de la Péninsule Ibérique. C'est la portion W.–S.W. de ce Massif qui forme l'unité la plus vaste.

Au Portugal, deux bordures céno-mésozoïques, de formes très irrégulières, encadrent ce Massif à l'Ouest et au Sud en se touchant presque dans la région côtière du Bas-Alentejo et de l'Algarve. Le vaste bassin cénozoïque Tage-Sado s'individualise pourtant de la bordure occidentale.

Il faut encore tenir compte, malgré sa faible étendue, de l'existence d'un tout petit archipel, comprenant deux groupes d'îlots, qui sont celui de Berlenga-Estelas et celui de Farilhões. On pense que ces îlots sont des vestiges du prolongement vers l'Ouest de terres plus vastes émergées qui auraient existé pendant les temps anté-jurassiques, et qui faisaient probablement partie du grand Continent Nord-Atlantique.

C'est dans le Massif Hespérique et dans cet archipel que se trouvent les terrains les plus anciens du pays, de l'Agnostozoïque et du Paléozoïque.

Pendant longtemps on a attribué à l'Archéen de vastes affleurements de roches métamorphiques, que l'on reconnaît aujourd'hui appartenir à des terrains plus modernes. Cependant, dans la plupart

des cas, il s'agit de formations d'âge indéterminé, de sorte qu'il est possible seulement de soutenir que quelques unes sont anté-siluriennes, et d'autres post-siluriennes.

Le sous-sol du Portugal ayant été affecté, parfois avec une remarquable intensité, par les orogénies huroniennes, hercyniennes et alpines, quelques palingenèses ont donné lieu à ce que divers terrains, de différents âges, offrent un même faciès archaïque. Le granite d'anataxie est fréquent.

Nous sommes sûrs qu'en certains locaux il y a des témoins de formations véritablement archéennes, ou, avec plus de probabilités, algonkiennes, mais nous ne possédons pas d'éléments suffisants pour les reconnaître spécifiquement et, même, souvent de les reconnaître comme ensemble agnostozoïque. La même chose se produit lorsqu'il s'agit du détail des effets des mouvements huroniens.

Il y a des références à un granite ancien, au moins antérieur au Silurien, et il existe des arkoses dans la partie inférieure de l'Ordovicien. On connaît également des orthogneiss bien plus anciens. Cela nous indique une granitisation qui, peut-être, a été huronienne, mais on ne sais rien des plissements formés par ces mouvements, pendant l'Agnostozoïque.

Tout cela résulte, en grande partie, de l'existence de vastes affleurements granitiques qui dispersent les lambeaux paléozoïques, et, aussi, du fait que le Cambrien indiscutable se présente au Portugal assez localisé et dans des aires relativement restreintes, où les fossiles rencontrés sont insuffisants pour nous indiquer s'il s'agit seulement du Géorgien, de l'Acadien ou bien des deux réunis, ce qui est, peut-être, plus naturel. Par contre, il n'y a pas d'éléments sérieux pour montrer l'occurrence du Potsdamien. À son tour la base du Silurien est en discordance sur les terrains qui sont plus anciens.

Il s'ensuit, dans bien des cas, que de puissantes formations existent, paléontologiquement stériles, dont on peut dire seulement qu'elles sont, sans doute, anté-ordoviciennes.

Pendant le dépôt des sédiments cambriens il semble y avoir eu un calme relatif, quoique troublé par des éruptions diabasiques.

La disposition des strates cambriennes et le fait que les assises ordoviciennes sont partout en discordance sur les formations sousjacentes, prouvent que pendant la première période de l'ére paléozoïque il y eut de remarquables actuations orogéniques. L'absence du Potsdamien paraît indiquer l'importance de la phase salairienne ou bohémienne.

Le Silurien, toujours marin, se rencontre complet, mais avec des variations de faciès, révélatrices du changement de la profondeur de la mer, notamment dans les passages de l'Ordovicien au Gothlandien, et de celui-ci au Gédinnien, dans lesquelles il est plus grossièrement détritique. Il y eut aussi quelques éruptions diabasiques. Tout ceci indique une période de distension, et de calme orogénique relatif.

Plus tard, l'actuation calédonienne s'est bien faite sentir. La phase cherusko-acadienne, sinon la phase dévonienne moyenne, qui établit la continuité entre les mouvements calédoniens et hercyniens, doit avoir une importance assez grande.

Le " bloc calédonien portugais," lequel est représenté aujourd'hui par tout le territoire anté-mesozoïque au Nord d'une bande de porphyres et de porphyrites, d'orientation N.W.–S.E., qui existe entre Évora et Beja est dû à l'action de l'une de ces phases ou bien à l'influence des deux réunies.

Dans ce bloc les formations marines plus récentes sont les coblenciennes. L'Anthracolithique s'y trouve toujours avec un faciès continental. Le Westphalien D et le Stéphanien moyen sont rencontrés dans la partie septentrionale. L'Autunien inférieur est isolé et dans la partie centrale du pays.

Outre ces faits, l'hypothèse présentée est justifiée par l'absence au Portugal du Mésodévonien et par l'existence, seulement au Sud de la limite ci-dessus indiquée, des formations marines du Néodévonien et du Carbonifère inférieur et moyen.

Il faut encore tenir compte du fait que parmi les éléments du conglomérat westphalien de l'Alentejo on trouve des porphyres et des porphyrites. L'affleurement de ces roches eruptives—qui traversent le Gothlandien—doit correspondre à la zone des fractures qui ont permis l'individualisation du block calédonien cité.

Il est probable que, pendant ces mouvements, des roches grenues, qui se rencontrent elles aussi représentées dans le conglomérat westphalien précité, aient été formées. Ce sont des granites, syénites,

diorites, tonalites et gabbros. Il est possible, évidemment, que quelques unes soient plus anciennes, mais d'autres de même type et dans la même région de l'Alentejo, ont métamorphisé le Cambrien, et parfois traversent le Gothlandien. Les gisements de magnétite de la même province sont naturellement dûs à ces activités magmatiques.

L'actuation des mouvements hercyniens est évidente quant à sa phase bretonne. Nous sommes obligés de supposer cela en vertu d'une lacune et d'une réduction de l'aire du Tournaisien supérieur, localisé à l'Occident et indiquant une régression assez importante après le dépôt du Néodévonien.

Il s'est suivi, alors, une large période de calme, pendant laquelle s'est étendue la grande transgression viséenne, dont les dépôts occupent une vaste surface en Alentejo et en Algarve.

Ces sédiments qui à l'Est reposent sur le Néodévonien, se continuent en succession normale avec d'autres, namuriens, puis moscoviens.

Plus tard, et sans doute dûe à la phase erzienne, une régression s'est initiée qui eut son point culminant à la fin de l'Anthracolithique inférieur et pour laquelle la phase asturienne a joué le principal rôle. C'est à ce moment qu'a été émergé ce que nous appelons " bloc hercynien portugais," qui correspond à l'aire antémésozoïque située au Sud de la bande des porphyres et porphyrites, déjà citée. C'est ainsi que le Massif Hespérique a atteint son unité.

Dans la zone des porphyres et des porphyrites, l'activité éruptive, qui a déterminé l'importante minéralisation pyriteuse du district de Beja, a du se prolonger encore.

Le granite qui se trouve représenté dans les arkoses et dans le conglomérat stéphaniens, ne doit pas être syntectonique de ce mouvement. Toutefois il est difficile de dire si le granite est calédonien ou huronien.

Cependant, une éruption porphyrique s'est réalisée dans les premiers temps du Stéphanien moyen, et peut contribuer à faire penser à une granitisation plus récente que l'Huronien.

Tout l'Anthracolithique continental se trouve très plissé, disloqué, et, en partie, traversé ou métamorphisé par le granite. Par contre, les plus anciens dépôts mésozoïques du Rhétien, sont en discordance sur l'Autunien. Il y eut, donc, actuation orogénique très importante à divers moments du grand espace de temps compris entre la fin du Permien inférieur et la fin du Trias, qui ont determiné, outre la formation de plissements appréciables, une importante granitisation. Celle-ci à son tour, donna lieu à une minéralisation de haute valeur—pegmatitique et hypothermale—de cassitérite, wolframite, sulfures, or et argent. Il est possible que certains minérais d'urane se soient formés alors, mais il semble que la plupart de ces derniers se sont formés à une époque ultérieure.

Des galets granitiques se rencontrent dans le conglomérat autunien, mais ce granite peut-être assez ancien, du même âge que ceux représentés dans les dépôts siluriens, westphaliens ou stéphaniens. Il n'est pas naturel que ce granite ait été mis en place pendant la phase ouralienne des mouvements hercyniques, car l'érosion n'aurait pas eu le temps de le faire affleurer ni de le désagreger avant l'Autunien.

Il y a, en vertu de ce qui précède, une grande difficulté à déterminer la phase la plus importante de la partie finale des mouvements hercyniens.

En général, tout le Paléozoïque antérieur à l'Autunien, présente, une direction de plis N.W.–S.E., déjà ébauchée par l'orogénie calédonienne, tandis que le premier étage du Permien montre une orientation de plis presque Nord-Sud. Il faut noter encore que l'Autunien ne se suit pas au Stéphanien, dont les affleurements sont séparés par de grandes distances. En outre, le Stéphanien supérieur n'est pas connu au Portugal. Ces faits justifient jusqu'à un certain point l'hypothèse selon laquelle la phase ouralienne aurait eu une importante actuation.

On doit dire, toutefois, que cette direction générale de plissement N.W.–S.E. varie beaucoup dans des cas particuliers, la tendance se vérifiant pour passer à la direction Nord-Sud près de la bordure céno-mésozoïque occidentale et Est-Ouest dans la zone frontière orientale. Il ne faut pas oublier encore que l'absence de sédiments autuniens au dessus des formations stéphaniennes peut être expliquée par des circonstances particulières, tels que, par exemple les mouvements épirogéniques locaux restreints, variations climatiques, etc.

Mais le cas du Stéphanien moyen qui a été métamorphosé par le granite dans cette région, et avec l'aspect que celui-ci présente, est de nature à faire réfléchir car nous ne devons pas oublier que l'on affirme avec assez d'assurance que ni pendant ni après le Carbonifère il n'y eut dans ces régions de sédimentation ni même un bassin permien, mais aucun jugement sûr ne peut-être formulé en raison des doutes encore existants au sujet de la genèse des formations granitiques en elles mêmes et encore plus quant aux conditions du milieu.

Si nous prenons aussi en considération ce qui s'était passé en Espagne, nous constatons que dans la plupart des cas il y eut continuité de sédimentation du Stéphanien à l'Autunien. Les deux étages se montrent presque partout concordants, tandis qu'il y a discordance par rapport au Saxonien.

Comme résultat de tout ceci et quoique l'on pense à l'existence d'une phase ouralienne au Portugal, nous estimons plus logique, faute de renseignements assez précis, d'admettre que la phase saalienne eut une plus grande importance, ayant été la cause de la granitisation hercynienne.

En dehors de toute hypothèse, nous sommes sûrs que le Massif Hespérique était constitué et consolidé avant la fin du Paléozoïque, offrant une plus grande étendue, et, avec assez de probabilités, rattaché au grand Continent Nord-Atlantique. L'actuel Archipel Berlenga-Estelas-Farilhões en aurait fait partie.

Comme il est fréquent, après les phénomènes orogéniques, pendant les périodes de distension qui leur succèdent des extrusions basiques se produisent. C'est ce qui s'est passé dans le Massif Hespérique On y voit, découpant et traversant le granite, des dikes ou des filons plus ou moins inclinés, de roches basiques, en général des dolérites, lesquels s'orientent suivant des directions variables mais principalement Est-Ouest. Il est probable que la mise en place des laccolites et sills de roches du même type qui en Algarve traversent l'Hettangien leur soient contemporaines.

Il n'est pas facile de déterminer l'âge des fractures qui ont permis le phénomène, ni celui de l'ascension du magma. Nous avons là une inconnue, résultant de l'absence de documentation relative au grand espace de temps compris entre l'Autunien et le Rhétien. Toutefois, la qualité des matériaux et leur position peuvent nous donner quelques indications. Les plus anciens terrains mésozoïques portugais ont été considérés comme triasiques, appartenant au Keuper et correspondant au commencement d'une transgression. En réalité leurs dépôts présentent un faciès continental et quelques fossiles rhétiens. Ces sédiments se continuent, en concordance, avec d'autres lagunaires, franchement hettangiens.

Il est naturel de supposer qu'à la suite de la formation de la chaîne hercynienne l'érosion soit devenue plus active. C'est ce que l'on constate en bien des points de l'Espagne, où des dépôts de faciès continental du Trias inférieur couvrent le Paléozoïque applani. Ainsi, il est probable que le même phénomène se soit produit au Portugal, mais comme dans cette partie de la Péninsule la transgression du Muschelkaek ne s'est pas faite sentir, les sédiments de ce dernier ne jouèrent pas le même rôle protecteur. Tout fut érodé et dispersé.

Les puissantes couches grossièrement détritiques du Rhétien portugais doivent aussi correspondre à une récidive très forte du travail érosif donc à un rajeunissement du relief immédiatement antérieur. D'après cela nous pensons à l'existence d'une appréciable actuation paléo-alpine, dans sa première phase Paléokimmérienne. Le mouvement, fondamentalement épirogénique, aurait permis les extrusions doléritiques postérieures, déjà mentionnées.

Pendant le Jurassique les conditions du milieu se sont modifiées avec lenteur, les dépôts hettangiens et sinémuriens offrant déjà les faciès indicateurs d'un commencement de transgression. Le caractère marin bien net ne se vérifie en tout cas que dans le Lotharingien.

Il se serait formé alors un grand golfe, allongé vers le Nord, entre le Massif Hespérique et son ancien prolongement, dont le petit Archipel des Berlenga-Estelas-Farilhões est le témoin.

La transgression liasique fut de grande amplitude et la ligne de rivage, à l'Est et au Nord, devait être assez éloignée de l'actuelle limite des dépôts, car on ne trouve pas de matériaux terrigènes même dans les petites enclaves situées au milieu des affleurements rhétiens et paléozoïques.

Cette mer de bordure s'est encore maintenue dans les premiers temps du Dogger. Une grande

régression s'est annoncée après, comme résultat elle aussi des activités paléo-alpines, en premier lieu dans la phase inter-Dogger, mais ensuite, avec plus d'intensité, dans les phases néo-kimmériennes. Ce sont celles-ci qui ont dirigés l'importante régression Malm-Néocomien. Le fond du golfe mésozoïque fut émergé alors dans la région au Nord de Sintra. Le même s'est produit en Algarve.

Il paraît que le Massif Hespérique s'est incliné vers le Sud-ouest en subissant une légère torsion, mouvement qui a orienté les accidents tectoniques postérieurs, d'une manière générale dans la direction N.E.–S.W.

Avec l'Aptien s'est ébauchée une nouvelle transgression qui eut sa plus grande amplitude pendant le Cénomanien, mais qui se poursuivit encore dans les premiers temps turoniens. Dans le Turonien moyen, après la formation des bancs de rudistes, apparaisent des matériaux charriés, indicateurs du commencement de l'émersion, effet de la phase ilséderienne des mouvements sub-hercyniens, lesquels se sont encore continués dans sa phase wernigerodienne, comme il est prouvé dans les dépôts fluvio-marins aturiens qui se superposent au Coniacien marin.

Ces mouvements sub-hercyniens ont dû être de grande importance. Outre le fait d'avoir déterminé la régression qui mit à découvert les bordures mésozoïques, et sûrement avec plus d'extension à l'Occident qu'au Sud, ils ont déterminé des plissements et des dislocations appréciables. C'est le cas du Sénonien marin ou fluvio-marin qui se trouve seulement au Nord du Mondego, et fait curieux, qui ne montre qu'une petite inclinaison vers le N.N.W., contrastant avec les autres formations du même groupe, y compris celles du Turonien, qui se présentent assez disloquées comme on le voit dans les anticlinaux et horsts de Palhaça, Mamarrosa, Cantanhede et Buarcos. Ces accidents quoiqu'ils aient une direction N.E.–S.W. présentent de grandes déviations, spécialement dans la région du Bas-Mondego où ils prennent la direction N.–S., E.–W., et même dans la chaîne de Boa Viagem, N.W.–S.E., comme si à l'occident il eut existé une zone de résistance qui eut donné lieu à ces déviations terminales.

Il est à supposer que c'est en résultat de ces mouvements que se sont formés le batholite granito-syénito-gabbroïque, de Sintra, le massif cupoliforme de Sines avec des gabbros, des diorites quartzifères et des syénites, et le laccolite de Monchique constitué par des syénites néphéliniques, pulaskites, etc.. L'âge précis de ces massifs est en tout cas inconnu. La seule chose que l'on peut garantir c'est que le premier est postérieur au Cénomanien, que le second est post-jurassique et que le troisième est plus moderne que l'Anthracolithique inférieur. Ce sont des raisons d'ordre géo-chimique, spécialement, qui permettent de considérer ce dernier massif comme synchronique des deux autres.

La détermination de l'âge de ces roches éruptives offre de sérieuses difficultés et fait surgir divers problèmes dont la discussion ne peut pas être faite ici. Nous présentons, donc, l'hypothèse la plus généralement acceptée.

À son tour, les complexes diapiriques, si caractéristiques des bordures céno-mésozoïques portugaises, eûrent sûrement alors leur principal mouvement, quoique les dislocations se soient continuées postérieurement, et quelquefois avec beaucoup d'intensité comme nous l'indiquerons plus tard.

Avec les derniers élans de l'orogénie paléo-alpine, notamment dans sa phase paléolaramienne, s'est accomplie l'émergence des bordures.

Nous ne connaissons que fort peu de choses du grand espace de temps compris entre la fin du Crétacé et le commencement du Neogéne. Il s'est produit, sans doute, d'importantes émissions basaltiques, dont on connait les épaisses coulées, qui alternent avec des dépôts pyroclastiques. Il est à supposer qu'elles se sont produites dans une période de distension et de calme orogénique relatif. On doit, toutefois, remarquer que les éruptions auraient pû commencer dès le Sénonien, car tout ce que l'on peut dire c'est que le basalte—en général olivinique—est postérieur au Turonien moyen.

Aux formations basaltiques se superposent des dépôts de conglomérats, qui servent de base aux argiles, grès et molasses des premiers niveaux du Miocène incontestable. C'est pour cela qu'on leur a attribué un âge oligocène.

Ces sédiments, si grossièrement détritiques, connus sous le nom de " conglomérats de Benfica," font croire à un antérieur rajeunissement de relief et à une réactivation érosive conséquente, lesquels

ont fait affleurer les massifs éruptifs cités, notamment celui de Sintra. En effet on trouve dans les formations de Benfica des roches provenant de cette montagne.

S'il en est ainsi, il est à supposer qu'une importante actuation de l'orogénie méso-alpine eut lieu, mais plus probablement dans ses dernières phases.

Les mouvements méso-alpins ont joué un important rôle dans la Péninsule Ibérique. En ce qui concerne le Portugal, il est malheureusement impossible de donner les détails de son activité, en raison des lacunes et de l'insuffisance de documentation paléontologique du Paléogène. Il est bon, toutefois, de penser qu'à ces mouvements-là on doit le ravivement du plus important relief du pays, celui même du vieux Massif Hespérique. En cela, les soi-disant " grès du Bussaco " d'âge incertain—les végétaux rencontrés peuvent aussi bien indiquer la fin du Crétacé que les premiers temps cénozoïques—marquent la limite inférieure de l'âge du plus ancien grand soulèvement produit par l'orogénie méso-alpine.

Il est impossible d'indiquer quelque limite supérieur, d'autant plus que d'autres mouvements, également d'une caractéristique épirogénique marquante, ont suivis, comme nous le ferons noter. Nous devons, toutefois, rappeler qu'une bonne partie du relief des bordures qui se présentent comme la continuation du principal relief du Massif Hespérique doit être plus ancienne. Nous pouvons donc, penser, comme la plupart des géologues espagnols, que la Chaîne Centrale Ibérique n'est pas le résultat d'une simple actuation restreinte d'âge alpin dans un avant pays, mais l'oeuvre d'un processus orogénique complexe qui a duré longtemps, car la chaîne en question se trouvait déjà en vue de soulèvement avant la grande transgression cénomanienne, soit pendant les mouvements paléo-alpins.

Le Miocène est marin, abondamment fossilifère, et se présente en concordance avec le soi-disant oligocène. Il y a, en tout cas, des doutes en ce qui concerne la représentation de l'Aquitanien.

À la première partie du Néogène a correspondu un calme orogénique et la transgression qui s'est alors produite fut ample, puisqu'elle a envahi une bonne partie des bordures, mais, principalement la vaste aire des bassins du Tage et du Sado. En bien des points la sédimentation eut lieu sur les formations paléozoïques.

On peut avoir une idée de l'importance et de l'activité des mouvements néo-alpins grâce aux variations et dislocations des dépôts miocènes.

On vérifie alors l'action des phases stairiennes en beaucoup de formations de l'Estremadura, de l'Alentejo et de l'Algarve. Notamment dans la Chaîne d'Arrabida les déformations furent très intenses. Ce fait est ici le résultat, surtout, de conditions particulières de la contrée, où les diastrophismes disharmoniques auraient pu avoir un plus grand développement dû à la plasticité, en premier lieu, des marnes héttangiennes, et, ensuite, des marnes bajociennes.

Le rôle le plus important appartient sans doute à la seconde phase stairienne, qui a conduit à la régression des derniers temps du Vindobonien.

Pendant une partie du Pontien il y eut de nouveau un calme relatif. Il y a lieu de croire que quelques manifestations magmatiques se sont produites alors. Ainsi on pense qu'en Algarve les basanites de la région Portimão-Lagos auraient métamorphisé l'Helvétien. On a même présenté l'hypothèse de toutes les roches melanocrates de l'Algarve occidental devaient être helvétiennes ou post-helvétiennes, sauf les roches doléritiques, mais ces faits n'ont pas été prouvés jusqu'ici.

Ce serait possible pour des formations éruptives en d'autres provinces, comme par exemple pour quelques roches des environs de Lisbonne, dont les filons semblent traverser le basalte paléogénique, et, ainsi, pour les dômes de gabbros sub-ophitiques du District de Leiria. L'ascension du magma de ces derniers aurait dû être facilité par le dispositif des complexes diapiriques. Pour ces gabbros tout ce que l'on peut affirmer c'est qu'ils sont postliasiques, car ils ont métamorphisé les formations de la série inférieure jurassique.

Les mouvements néo-alpins dans leur phase rhôdanienne ont dû se faire sentir, en général, avec peu d'intensité, bien que l'on connaisse des dislocations qui doivent leur être attribuées.

Au nouveau calme a correspondu la transgression pliocène, qui, probablement, n'a pas eu une aussi grande extension que l'antérieure. Toutefois, la ligne de rivage devait se trouver bien en-deçà de l'actuelle.

Les formations plaisanciennes et astiennes furent troublées postérieurement. La phase paléo-walachienne s'est ainsi mise en évidence. Après une petite régression, se placerait la transgression, que nous sommes obligés de considérer calabrienne.

Pendant la régression, déterminée par la phase finale néo-alpine, il y eut un appréciable rajeunissement de relief avec formations d'importants dépôts de fanglomérats. Un soulèvement général du pays s'est initié alors et s'est continué pendant l'Anthropozoïque avec quelques perturbations, plus ou moins localisées, conditionnées par les effets des orogénèses antérieures.

Les relations entre les formations pliocènes et pleistocènes ne sont pas assez précises en bien des cas par suite du manque de fossiles. Il est donc difficile d'avoir une idée claire sur l'évolution géomorphologique du pays après la fin de la transgression plaisancienne.

On connaît des niveaux d'anciennes plages à différentes altitudes, et qui atteignent en divers points les valeurs suivantes: 160 m., 130 m., 110 m., 80 m., 60 m., 30 m., 15 m., 6 m. À ces plages correspondent des terrasses fluviales étagées dont les plus hautes sont à 130 m., quoique avec des variations importantes peuvent y être notées dans certains cas. Les dépôts correspondants au niveau de 90 m. ont été attribués, en général, au Sicilien, donc au début du Pleistocène.

S'il en est ainsi, la détermination de l'âge des trois autres niveaux plus élevés poserait des problèmes très délicats.

Nous ne savons rien de positif à l'égard du mécanisme de la formation de ce type de plages. La question des variations du niveau de la mer, a soulevé partout de sérieuses controverses dont la discussion ne peut pas être reprise dans cette si courte communication.

Il est natural qu'il y eut des variations de ce niveau dans l'un ou l'autre sens, mais il est bon de penser, qu'à partir du Calabrien, le mouvement se traduit dans une régression presque continue, quoique avec quelques oscillations positives et stationnements plus ou moins longs. Il y eut, ainsi, un enfoncement général des réseaux hydrographiques. Il faut remarquer toutefois que la récente transgression flandrienne est très nette.

Une seule glaciation est reconnue au Portugal, celle du Würm, dont on rencontre des témoins certains dans la Chaîne d'Estrela.

Il y dû y avoir pendant l'Anthropozoïque quelques mouvements de réajustement isostatique, qui ont produit des dénivellations entre des blocs contigus, ainsi qu'on peut le vérifier en quelques lieux et notamment dans le Minho.

SUR LES RELATIONS STRATIGRAPHIQUES, STRUCTURALES ET MAGMATIQUES ENTRE LE MASSIF CENTRAL FRANÇAIS ET L'ARMORIQUE MÉRIDIONALE

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RÉSUMÉ

Dans le Limousin septentrional et dans l'Armorique méridionale, j'ai observé des zones de plis isoclinaux, déversés vers le Sud, en partie zones de racines, puis, au sud d'un anticlinal fondamental, une zone affectée par des plis secondaires, où apparaissent les traces de mouvements tangentiels.

Il y a liaison stratigraphique entre le Paléozoïque, en partie métamorphique, de l'Armorique méridionale et le Cristallophyllien du Limousin.

Les zones structurales du Limousin peuvent être suivies dans l'Armorique méridionale.

La liaison des granulites, d'orthogneiss ou gneiss d'injection laminés, de granite calco-alcalin profond, du type de Guéret, associé à des migmatites, enfin de diorites quartzifères à amphibole apparaît clairement.

Ainsi se trouvent établies ou confirmées des données essentielles sur l'âge paléozoïque du métamorphisme dans l'Armorique méridionale et dans le Limousin, sur l'âge probablement carbonifère des granulites et des granites profonds du Massif Central, enfin sur la continuité des grandes structures dans la chaîne hercynienne, depuis l'Armorique occidentale jusqu'à la bordure est du Massif Central et même probablement jusqu'en Bohême.

La liaison du Massif Central Français et de l'Armorique est classique depuis longtemps, puisqu'elle a été définie en 1885 par Ed. Suess et précisée en 1887 par Marcel Bertrand; mais elle n'a été envisagée jusqu'à une date récente que pour le Paléozoïque non métamorphique et, dans le Massif Central, seulement pour la phase orogénique post-stéphanienne.

En 1934 (Demay, 1934 a et b), j'ai défini cette liaison pour les phases essentielles et pour les formations cristallophylliennes comme pour les sédimentaires.

Un peu plus tard, Gilbert Mathieu, qui avait mis en évidence des données nouvelles importantes sur la région vendéenne (Mathieu, 1937), a tenté en 1945 (Mathieu, 1945) un raccord entre le Limousin et la Vendée.

C'est seulement à partir de 1946, après avoir consacré vingt ans de recherche à l'étude des parties hercynienne et précambrienne du Massif Central, que j'ai essayé de préciser cette liaison axiale, en étudiant sur le terrain, non plus seulement le Bas-Limousin, mais le Limousin septentrional, prolongement axial exact de la région vendéenne, puis cette région vendéenne, enfin plus à l'Ouest cette partie méridionale de l'Armorique qui a fait l'objet des travaux magnifiques, mais anciens, de Charles Barrois et où il a fallu définir les structures avant de faire les comparaisons.

I. RELATIONS STRATIGRAPHIQUES

Du côté armoricain, j'ai pu constater, en accord avec les conclusions de G. Mathieu, que, dans la région vendéenne, le Paléozoïque non métamorphique, bien daté, grâce à la découverte de fossiles par G. Mathieu dans le niveau des schistes d'Angers et à l'existence de faciès caractéristiques du grès armoricain et du Cambrien supérieur, passe sans discontinuité à des schistes et grès, parfois avec phtanites, classés dans le Briovérien, à des schistes séricíteux, à des micaschistes et à des amphibolites.

Le Briovérien de Vendée, d'après G. Mathieu, comprendrait du Précambrien, du Géorgien et de l'Acadien (Mathieu 1945).

À l'Ouest de la région vendéenne, mais toujours dans l'Armorique méridionale, en particulier dans la région comprise entre Ancenis, Redon, Baud et la côte, mes observations récentes, encore inédites, semblent prouver que les micaschistes et gneiss comprennent des termes plus élevés du Paléozoïque: grès armoricain et schistes d'Angers, de l'Ordovicien, schistes ampéliteux et quartzites, avec phtanites, calcaires et tufs de Rosan, du Gothlandien.

De l'autre côté du Poitou, dans le Massif Central, les micaschistes et amphibolites des trois grandes zones synclinales du Limousin, dont les deux septentrionales ont un prolongement axial certain dans la région vendéenne, sont identiques aux formations métamorphiques de la région vendéenne. Les micaschistes du Limousin septentrional deviennent progressivement à l'Ouest très peu métamorphiques; ils comprennent des schistes graphiteux et des quartzites.

Quant au troisième synclinal, celui de Lanouaille ou du Bas-Limousin, dont le prolongement est masqué par le Mésozoïque jusqu'à l'Atlantique, les micaschistes et amphibolites y comprennent des calcaires, où Maurice Roques a découvert des entroques et qui sont probablement cambriens ou siluriens et plus vraisemblablement siluriens, d'après une remarque de M. Thoral.

On doit donc conclure qu'il existe une liaison stratigraphique étroite entre la série cambro-silurienne et briovérienne, en partie métamorphique, de Vendée et les schistes sériciteux, micaschistes et gneiss du Limousin.

Ceux-ci doivent être attribués, soit entièrement au Paléozoïque, soit à un ensemble d'âge paléozoïque et précambrien supérieur, ne comportant pas de discordance appréciable à la base du Paléozoïque. Enfin, le métamorphisme régional y est, comme dans la région vendéenne, d'âge paléozoïque.

Si l'on tient compte de la disposition des zones axiales en arcs concentriques, que j'ai mise en évidence dans le Massif Central (Demay, 1934 b), on voit que cette conclusion rejoint celles auxquelles j'ai abouti de manière probable, à l'autre extrémité de ces arcs, dans le Forez et dans la zone lyonnaise et, de manière certaine, dans les arcs méridionaux du Massif, en particulier dans la région de l'Aigoual et du Vigan.

II. RELATIONS STRUCTURALES*

(*a*) *Aperçu sur la structure du Limousin.*—Mes recherches récentes dans le Limousin, et, pour la partie méridionale, les données anciennes, dues surtout aux travaux de G. Mouret, me permettent d'y distinguer, du Sud au Nord, à partir du synclinal de Lanouaille, les grandes formes structurales suivantes, que je ne peux décrire ici: synclinal de Lanouaille (1); anticlinal de Tulle (2); synclinal d'Uzerche (3); anticlinal de Masseret (4); synclinal de St.-Germain-les-Belles (5); anticlinal de Rochechouart, Limoges, Nord de St.-Léonard, Bourganeuf (6), qui se prolonge probablement, au delà de la faille d'Argentat, dans la zone granulitique de Millevaches; zone synclinale d'Availles-Limouzine, Confolens, Roumazière (7), à structure isoclinale, déversée vers le Sud; anticlinal large de la Jonchère (8); zone synclinale de l'Isle-Jourdain et de Bellac (9), à structure isoclinale, souvent redressée, parfois verticale, déversée vers le Sud, qui se prolonge sur le bord sud du granite de Guéret, au nord de Laurière, et probablement, au-delà de la faille d'Argentat, dans la zone granulitique de Millevaches; anticlinal de Magnac-Laval et du Dorat (10), bien accusé par la présence d'un granite profond, qui prolonge le granite de Guéret et se trouve associé, comme lui, à des migmatites, parfois du type des gneiss d'Aubusson, et par le pendage Sud modéré sur son flanc Sud.

La zone 9 correspond à une zone de racines, d'où les plis ont déferlé vers le Sud. L'allure isoclinale de la zone 7 correspond peut-être à un phénomène analogue ou doit être attribuée à un plissement secondaire intense, accusant le même sens de poussée.

Dans les zones 6 à 2, la répartition du degré métamorphique est, dans l'ensemble, normale; mais plusieurs observations m'ont permis d'établir que des mouvements tangentiels importants, avec formation de plis couchés de détail, par exemple à St.-Denis-les-Murs, et laminage de couches peu

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* On pourra suivre cet exposé sur la carte géologique au 320.000e (feuilles de Nantes et Brest-Lorient), sur la carte de France au 1.000.000e, sur le schéma structural (fig. 1) et sur les coupes (fig. 2) de la présente note.

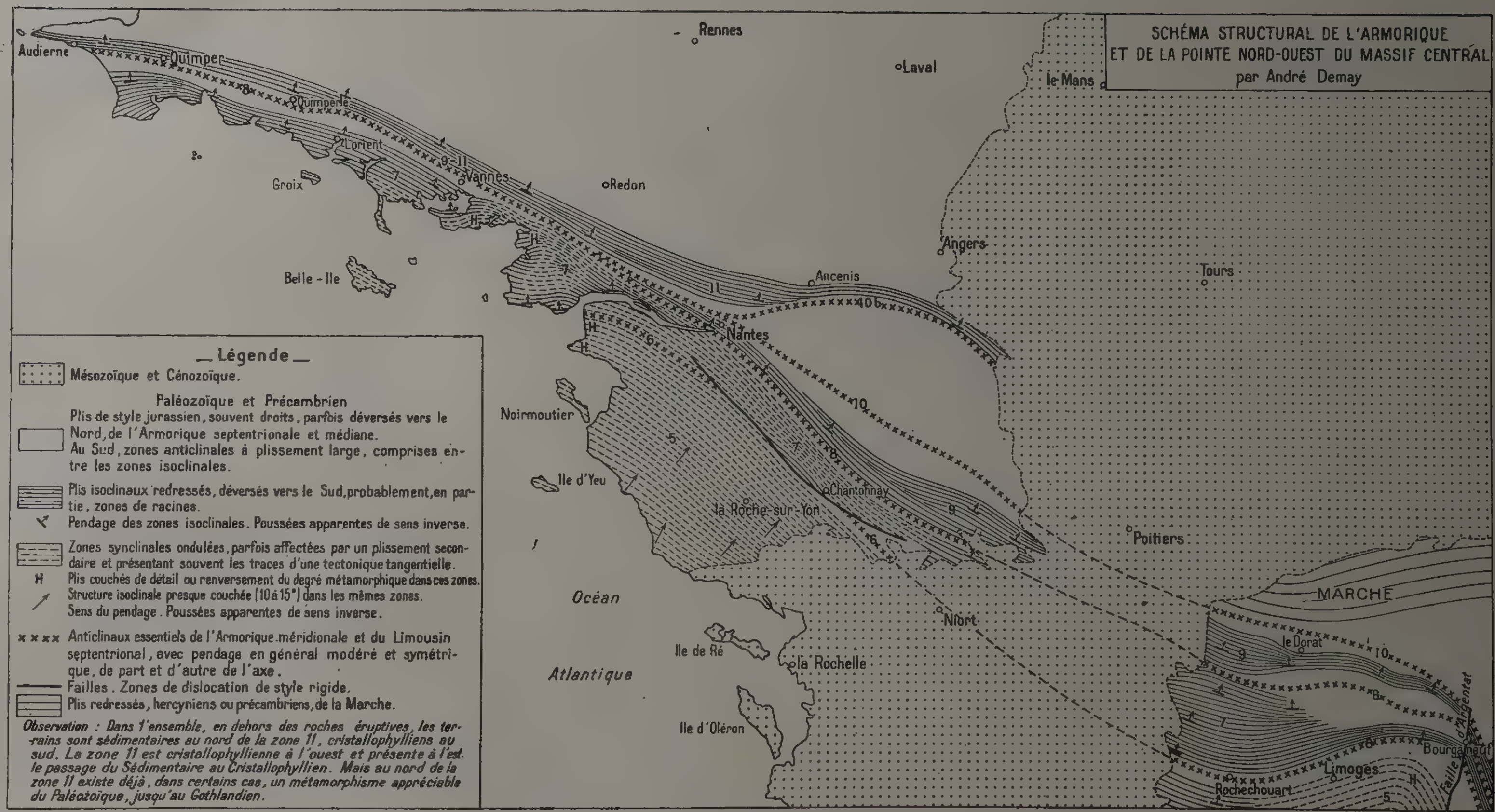


SCHÉMA STRUCTURAL DE L'ARMORIQUE
ET DE LA POINTE NORD-OUEST DU MASSIF CENTRAL
par André Demay
Audierne
Quimper
Quimperlé
Lorient
Groix
Vannes
Belle-Ile
Redon
Rennes
Laval
le Mans
Angers
Ancenis
Tours
Nantes
Noirmoutier
Ile d'Yeu
Chantonnay
la Roche-sur-Yon
Poitiers
Océan
Atlantique
Niort
Ile de Ré
la Rochelle
Ile d'Oléron
MARCHE
le Dorat
Bourganeuf
Limoges
Rochechouart
Faille d'Argentat
— Légende —
Mésozoïque et Cénozoïque.
Paléozoïque et Précambrien
Plis de style jurassien, souvent droits, parfois déversés vers le Nord, de l'Armorique septentrionale et médiane.
Au Sud, zones anticlinales à plissement large, comprises entre les zones isoclinales.
Plis isoclinaux redressés, déversés vers le Sud, probablement, en partie, zones de racines.
Pendage des zones isoclinales. Poussées apparentes de sens inverse.
Zones synclinales ondulées, parfois affectées par un plissement secondaire et présentant souvent les traces d'une tectonique tangentielle.
H Plis couchés de détail ou renversement du degré métamorphique dans ces zones.
Structure isoclinale presque couchée (10 à 15°) dans les mêmes zones.
Sens du pendage. Poussées apparentes de sens inverse.
x x x x Anticlinaux essentiels de l'Armorique méridionale et du Limousin septentrional, avec pendage en général modéré et symétrique, de part et d'autre de l'axe.
Failles. Zones de dislocation de style rigide.
Plis redressés, hercyniens ou précambriens, de la Marche.
Observation : Dans l'ensemble, en dehors des roches éruptives, les terrains sont sédimentaires au nord de la zone 11, cristallophylliens au sud. La zone 11 est cristallophyllienne à l'ouest et présente à l'est le passage du Sédimentaire au Cristallophyllien. Mais au nord de la zone 11 existe déjà, dans certains cas, un métamorphisme appréciable du Paléozoïque, jusqu'au Gothlandien.

FIG. 1.

inclinées, ont eu lieu avant le plissement secondaire en synclinaux et anticlinaux, souvent à peu près symétriques.

(*b*) *Structure de l'Armorique méridionale. Relations structurales avec le Limousin.*—Les zones méridionales (1 à 4) du Limousin n'ont pas de prolongement en Armorique, parce que leur prolongement occidental est masqué par le Mésozoïque jusqu'à l'Atlantique.

Le synclinal de St.-Germain-les-Belles (zone 5) se prolonge dans la zone synclinale de la Vendée occidentale, dont l'axe est probablement le synclinal des Lucs (noyau de schistes roses, encadrés par des micaschistes, et disposition symétrique des pendages).

Mais, tandis que dans le flanc Sud, apparaît en Vendée une structure isoclinale, écailles ou plis déversés, presque couchés vers le Sud, dans le Limousin, je n'y ai observé une structure isoclinale, également déversée vers le Sud, qu'à l'extrémité Ouest, au Sud de Rochechouart (fig. 2 coupe IV). Dans le flanc nord, pour les deux régions, si l'ordre de superposition semble normal, les traces de mouvements tangentiels sont visibles. Il est frappant d'observer, par exemple, à l'ouest de Chantonnay, en Vendée, et près de la Croisille, dans le Limousin, des gneiss d'injection laminés qui reposent sur des micaschistes et correspondent probablement à une injection laccolitique, accompagnée ou suivie de mouvements tangentiels, plutôt qu'à un véritable renversement.

L'anticlinal de Rochechouart (zone 6) a un prolongement certain dans l'anticlinal des Essarts, de la région vendéenne, comme l'a déjà noté G. Mathieu. Mais il faut en voir à mon sens, le prolongement oriental, non pas vers St.-Yrieix, mais vers Limoges, St.-Léonard et Bourganeuf.

J'ai pu suivre facilement l'anticlinal des Essarts à l'Ouest, jusqu'à l'embouchure de la Loire, dans la région de St-Brévin, où il est bien marqué par la présence de migmatites granitiques et de granite profond à biotite et par des pendages symétriques peu élevés. Le flanc nord apparaît près de Donges, sur la rive droite de la Loire, et sur la côte de St-Nazaire et du Pornichet. Il disparaît dans l'Atlantique au Sud du Croisic.

La zone synclinale d'Availles-Limouzine, Confolens, Roumazières (zone 7), à plis isoclinaux déversés vers le Sud, a un prolongement certain dans la zone synclinale de Chantonnay, qui comprend le Silurien fossilifère, découvert par G. Mathieu, et du Cambrien.

Dans cette zone, la partie orientale, la plus proche du Limousin, présente, comme la zone 7, des plis isoclinaux poussés vers le Sud (de St-Maixent à Champdeniers). La partie occidentale comporte seulement des failles longitudinales, qui ne sont pas des failles inverses, ni des surfaces de poussée; pourtant, un plissement isoclinal, avec poussée vers le Sud, reparaît dans le Sud de cette partie occidentale, à l'ouest de Sigournais.

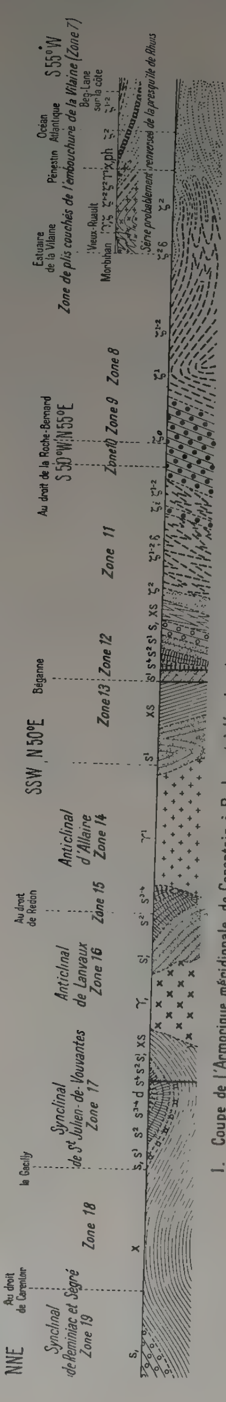
Le synclinal de Chantonnay, bute, pour une part, contre l'accident du sillon de Bretagne et, pour une autre part, se prolonge, mais sans Paléozoïque daté, au Sud de Montaigu-Vendée, puis au Nord du lac de Grand-Lieu, passe au Sud de la Loire près du Pellerin et, de manière probable, dans la Grande-Brière (micaschistes et gneiss, avec phtanites et cipolins, à plongée Nord-Est).

Plus à l'Ouest encore, cette zone s'élargit et couvre d'assez grands espaces dans la région de l'embouchure de la Vilaine, puis au Sud de Vannes et d'Auray, enfin à l'Est de la baie d'Audierne.

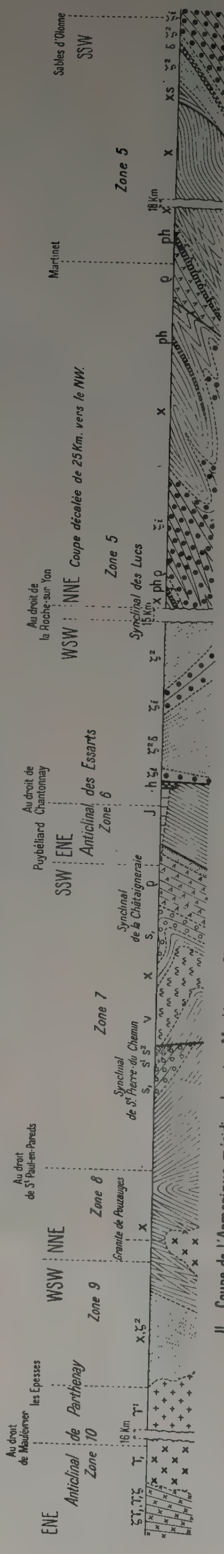
J'ai observé dans cette zone, d'une part, une puissante série de plis isoclinaux, poussés vers le Sud, plis de la baie d'Audierne, des régions de Pont-l'Abbé, Concarneau, Lorient, Auray et du Morbihan, souvent pour les deux dernières avec absorption magmatique syntectonique, d'autre part, des parties couchées, à plongée faible ou moyenne, où des structures de détail (plis couchés à l'Est de Pénestin, surface de chevauchement avec écrasement à l'Ouest de Pénestin) et le laminage intense de couches subhorizontales prouvent l'existence de mouvements tangentiels.

Le renversement du degré métamorphique dans des paragneiss et micaschistes indique même, de manière probable, une véritable nappe, dans la presqu'île de Rhuis.

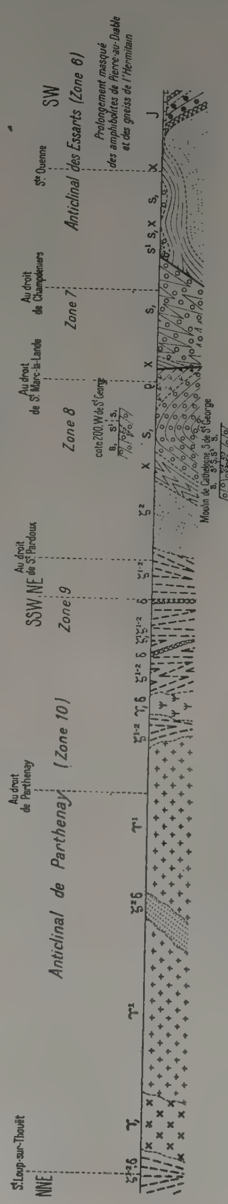
Axialement, les plis isoclinaux, assez redressés, de Lorient, d'Auray et du Morbihan, se prolongent dans la zone couchée de l'embouchure de la Vilaine. Ils représentent, soit une zone de plissement secondaire intense, soit une zone de racines, d'où proviendrait en particulier la nappe de Rhuis, et qui s'amortirait vers le Sud, feston plus méridional que ceux de la Bretagne orientale, suivant un mode



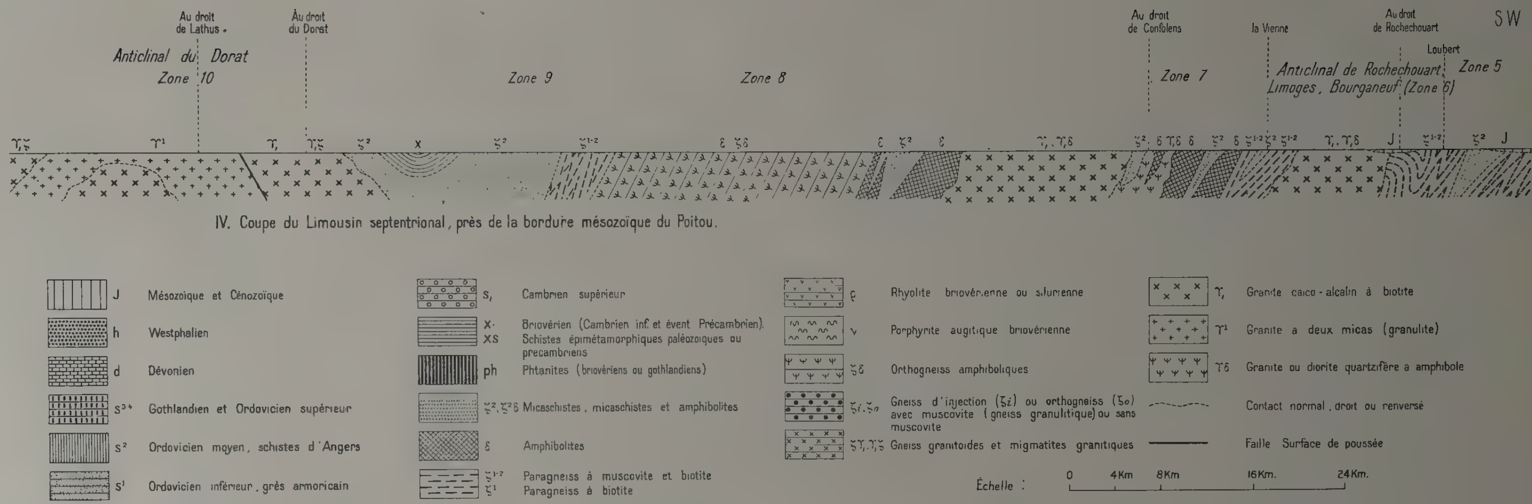
I. Coupe de l'Armorique méridionale, de Carentoir à Redon et à l'embouchure de la Vilaine.



II. Coupe de l'Armorique méridionale entre Mauléverier, Châtillon-sur-Sèvre et la côte vendéenne.



III. Coupe de l'Armorique méridionale, près de la bordure mésozoique du Poitou, entre St Loup-sur-Thouët, Parthenay et Ste Ouenne.



Documents consultés : *Cartes géologiques au 80 000^e et au 320.000^e. Tracés inédits de A. Demay au 80.000^e. Pour le Cambrien et le Silurien du synclinorium de Chantonnay et pour la Vendée occidentale, les coupes ont été dessinées d'après des coupes de G. Mathieu, avec quelques modifications.*

Observations : *La définition des zones numérotées, indiquées sur les coupes, figure dans le texte de la Note. On remarquera que la structure apparente varie parfois, pour une même zone, dans les différentes coupes diamétrales, bien que cette zone ait pu être suivie avec certitude sur le terrain, en direction axiale. Ces variations résultent, dans certains cas, d'un plissement plus intense, parfois isoclinal, dans des segments soumis à un serrage plus fort. Dans d'autres cas, une zone à structure tangentielle se prolonge dans une zone d'apparence normale, affectée seulement par un plissement secondaire. C'est ainsi que la zone 7 se prolonge dans le synclinorium de Chantonnay. Dans ce cas, il est probable que des plis couchés ont déferlé sur la zone à superposition normale ou qu'il existe une structure tangentielle en profondeur, ou les deux à la fois.*

FIG. 2.

dont M. Gignoux a montré la réalité dans les Alpes. Dans le première hypothèse, les parties couchées s'enracineraient au Nord de l'anticlinal de Quimperlé, dans la zone 9, comme celles de la Bretagne orientale.

L'anticlinal de la Jonchère, (zone 8), marqué par les pendages et souligné par des granulites, a un prolongement probable du côté vendéen, dans un anticlinal marqué lui aussi seulement par les pendages, sorte de genou entre le flanc Nord du synclinal de Chantonnay, à plongée Sud, et une zone isoclinale à plongée Nord, qui sera décrite ci-dessous.

L'axe anticlinal passe près de St Paul-en-Pared (Sud des Herbiers), puis au Nord de Montaigu-Vendée (retombée sud bien accusée entre Montaigu et St-George). Il rejoint ainsi, de manière probable, l'anticlinal de Basse-Indre, que j'ai observé sur la rive droite de la Loire.

Celui-ci se prolonge de manière certaine dans la région de Pont-Château, puis dans le genou* au Sud des plis isoclinaux de la Roche-Bernard et de Muzillac, enfin dans un anticlinal de fond très important, l'anticlinal de Brech et Quimperlé, bien défini, au Nord de Vannes, par les pendages et par la présence de migmatites granitiques et de granite profond à biotite et qui est marqué par les pendages jusqu'à l'Atlantique, au Sud d'Audierne, coïncidant là à peu près avec l'anticlinal de Cornouaille de Ch. Barrois, évoqué récemment par F. R. Giot.

La zone isoclinale de l'Isle-Jourdain et de Bellac, poussée vers le Sud (zone 9), se prolonge dans une zone de plis redressés parfois subverticaux, souvent poussés vers le Sud, entre St-Pardoux et Secondigny, dans le Bocage vendéen, puis sur le bord Sud du massif granitique de Pouzauges, enfin entre ce massif et les Herbiers.

J'ai pu suivre cette zone jusqu'à la coupe de la Loire, où elle est définie par d'excellents affleurements, à Nantes même et entre Nantes et Couëron et, bien plus à l'Ouest, dans la zone de plis isoclinaux redressés de la Roche-Bernard et de Muzillac, enfin jusqu'à Pluvigner, au Nord d'Auray, bien marquée partout par des orthogneiss et gneiss d'injection redressés à plongée Nord.

Souvent, dans cette zone, il apparaît que des termes de degré métamorphique élevé et des orthogneiss sont déversés sur des termes de degré moindre. En Armorique, comme dans le Limousin, ce n'est pas une zone synclinale simple, mais une zone de plis redressés, avec de puissantes injections magmatiques syntectoniques, probablement une zone de racines.

La zone 10, marquée dans le Limousin par le massif de granite et migmatites granitiques de Magnac-Laval et du Dorat, se prolonge en Vendée par l'anticlinal de Parthenay, défini par G. Mathieu, puis par l'anticlinal de Châtillon-sur-Sèvre, dont l'axe est largement absorbé par de la granulite, mais qui comprend, sur les deux flancs, des granites à biotite. Celui du flanc Nord, que j'ai observé en particulier près de Voutegon et au Sud d'Argenton-Château, présente un faciès identique à celui du granite du Dorat et à celui du granite de Guéret et est associé aux mêmes migmatites granitiques.

J'ai suivi cet anticlinal au Nord de Clisson et de Vertou et ai reconnu son passage dans la coupe de la Loire, entre Mauves et Nantes. Il vient se terminer en pointe près de Pont-Château.

Au Sud de la Loire, il faut lui adjoindre un large épanouissement, d'allure onduleuse, qui va de Thouars à Chemillé et Beaupréau, troublé seulement par un repli synclinal étroit, d'Airvault à Argenton-Château et l'Ouest de Cholet.

Au Nord de cette zone largement ondulée de Vihiers, Chemillé, Beaupréau et d'un anticlinal, dont l'axe, noté 10 *b* sur le schéma structural de figure 1, rejoint à l'Ouest l'axe de l'anticlinal 10, existe en Armorique un faisceau de plis isoclinaux, souvent très redressés, déversés vers le Sud (zone 11), qui engagent, au Sud, du Cristallophyllien, au moins en partie paléozoique, et, au Nord, du Paléozoïque épimétamorphique ou non métamorphique, daté du Silurien au Dinantien, qui appartient au synclinal d'Ancenis.

La coupe de la Loire révèle clairement cette structure. Le prolongement axial de cette zone 11 dans le Massif Central reste incertain. Peut-être, par suite du resserrement de l'anticlinal précédent,

* C'est par ce genou que se fait la liaison avec la zone couchée de l'embouchure de la Vilaine.

vient-elle passer immédiatement au Nord du granite du Dorat, ou au contraire, masquée par le Mésozoïque, échappe-t-elle au Massif Central.

Vers l'Ouest, j'ai observé au contraire, avec certitude, le prolongement de ces plis isoclinaux de la zone 11 dans la région de Drefféac (micaschistes et amphibolites à forte plongée Nord) et, pour la partie sédimentaire ou épimétamorphique, dans la région de St-Gildas et de Sévérac. Par suite du resserrement et de la disparition de l'anticlinal 10, ces plis, à partir de Pont-Château, viennent s'accoler à ceux de la zone 9 et en sont inséparables plus à l'Ouest.

En tout cas, tous les plis armoricains, au Nord des plis serrés de Drefféac et St-Gildas, ont un prolongement oriental qui s'ennoie sous le Mésozoïque et échappe au Massif Central, au moins dans sa partie Ouest.

Ce n'est pas le lieu ici de décrire ces synclinaux et anticlinaux. Il suffit d'indiquer que ce sont des plis, parfois presque symétriques, tout au moins dans la partie orientale de l'Armorique. Certains synclinaux ont même une allure très large. Vers l'Ouest, ces plis se resserrent et plusieurs d'entre eux, par exemple l'anticlinal de Lanvaux et le synclinal de Baud-Malestroit, prolongement du synclinal d'Angers, prennent une allure isoclinale, poussée vers le Sud.

Plus au Nord et même, dans la partie orientale, déjà pour le synclinal d'Angers, l'Armorique présente une structure que les travaux d'Oehlert, Ch. Barrois, A. Bigot, P. Pruvost, Y. Milon, J. Péneau et de bien d'autres géologues ont rendue classique.

Elle est caractérisée par des plis souvent à peu près symétriques, avec des failles longitudinales et parfois par des plis encore assez larges, mais déversés vers le Nord.*

Si l'on fait abstraction des granites hercyniens intrusifs, qui donnent à l'Armorique septentrionale un caractère bien différent de celui du Jura, c'est, au point de vue structural, approximativement un style jurassien.

Je suis ainsi conduit à distinguer, au Nord, une Armorique jurassienne, avec un socle précambrien dans la partie la plus septentrionale, puis une zone de plis serrés, souvent redressés, poussés vers le Sud, que séparent des anticlinaux plissés de manière large, enfin une zone onduleuse, parfois sub-horizontale, où apparaissent des traces certaines de mouvements tangentiels, peut-être une véritable nappe dans la presqu'île de Rhuis, et, en Vendée occidentale, des plis isoclinaux presque couchés.

Au Sud de l'Armorique jurassienne, parfois même déjà dans sa lisière méridionale, le Paléozoïque passe à des formations épimétamorphiques, puis nettement cristallophylliennes.

Les principales zones d'enracinement des plis qui se couchaient vers le Sud semblent être, du Nord au Sud, la zone 11, que l'on peut suivre d'Audierne à Chalonnes et Thouarcé, au sud d'Angers, puis la zone 9, accolée d'ailleurs à la zone 11 dans l'Armorique occidentale, enfin, dans la zone 7, s'il ne s'agit pas d'un plissement isoclinal secondaire, un feston plus méridional également poussé vers le Sud, celui de la baie d'Audierne, de Lorient, d'Auray et du Morbihan, qui s'amortit à l'Est, mais semble reparaître dans le Bocage vendéen, au Nord de l'anticlinal des Essarts.

C'est seulement cette Armorique méridionale, dont nous retrouvons le prolongement axial dans le Massif Central.

A l'exception de la zone 11, dont le prolongement dans le Massif Central est incertain, on a vu plus haut comment il était possible de raccorder toutes les zones structurales de l'Armorique méridionale à des zones analogues dans le Limousin (zones 5 à 10).

La signification de ces raccords pour la tectonique générale de la chaîne hercynienne sera dégagée dans les conclusions.

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* Les belles observations de P. Pruvost, G. Waterlot, P. Comte (Pruvost, 1943) sur un métamorphisme postérieur au Dinantien inf. entre Brest, Morlaix et St-Efflam, posent un problème qui ne peut être examiné ici. Mais la structure qu'ils ont définie, celle d'un pli déversé vers le Nord, est conforme à ce qui peut être observé en d'autres parties de l'Armorique septentrionale ou médiane.

III. RELATIONS MAGMATIQUES

(*a*) *Granite à deux micas ou granulite.*—Si l'on tient compte des caractères lithologiques et des liaisons structurales établies au paragr. II, il est impossible de douter que les massifs granulitiques de l'Armorique méridionale sont le prolongement de ceux du Limousin et de la Marche.

Mais dans chaque région, il n'y a pas liaison axiale précise avec une seule zone orogénique.

(*b*) *Orthogneiss et gneiss d'injection à grands feldspaths, laminés et plus ou moins recristallisés.*—

J'ai observé dans le Limousin ces divers types et, en Armorique, des faciès qui correspondent exactement à l'un ou l'autre de ceux-ci, par exemple gneiss d'injection fortement laminés du flanc Sud de l'anticlinal des Essarts, en Vendée, qui, à 200 km. de distance, est dans le prolongement axial de celui de la Croisille, dans le Limousin, orthogneiss de la Roche-Bernard, Muzillac, Pluvigner, massif important qui s'allonge dans les zones orogéniques, ici accolées, 9 et 11.

Pour ces massifs, fortement engagés dans l'orogenèse hercynienne, la liaison axiale de l'Armorique et du Massif Central semble plus stricte que pour les granulites.

(*c*) *Granites à biotite, à faciès voisin de celui de Guéret, associés à des migmatites calco-alcalines et en général syntectoniques.*—J'ai constaté que les granites de ce type et des migmatites associées constituent le coeur de tous les grands anticlinaux du Limousin méridional et septentrional. Ce sont des granites profonds ou parfois des apophyses intrusives de ces granites.

A l'extrémité Ouest de l'anticlinal de Bourganeuf-Limoges-Rochechouart (zone 6), le granite de Chabanais présente exactement le faciès de Guéret. Quant à l'anticlinal du Dorat (zone 10), j'y ai observé, jusqu'au Mésozoïque du Poitou, un granite identique à celui de Guéret, avec des migmatites granitiques, souvent du type des gneiss d'Aubusson. Il prolonge d'ailleurs axialement le granite de Guéret.

Du côté armoricain, j'ai observé des granites profonds, syntectoniques, associés à des migmatites, tout à fait analogues à ceux du Limousin et qui, pour une part, en représentent certainement le prolongement axial.

Le plus proche du Limousin est le granite de Voutegon, associé à des migmatites granitiques et à des gneiss granitoïdes, qui affleure entre St Loup-sur-Thouët, Argenton-Château et le Sud de Cholet, dans le prolongement axial du granite du Dorat (zone 10). Le granite de Moncoutant, Pouzauges, Cerizay, de la région vendéenne (zone 9) présente un facies analogue, parfois à plus gros grain, mais est logé plus haut, peut-être en laccolite, à la manière des granites intrusifs du Massif Central, liés aux granites profonds.

L'anticlinal des Essarts (zone 6) montre, non pas dans la région vendéenne, où le terme magmatique le plus profond est le gneiss d'injection évoqué ci-dessus, mais plus à l'Ouest, le granite calco-alcalin à biotite et les belles migmatites granitiques de St-Brévin, du Sud de Paimboeuf et de Donges, sur la rive droite de la Loire, avec replis multiples et absorption syntectonique.

L'anticlinal de Quimperlé (zone 8) ne montre ses termes profonds qu'au Nord de la Vilaine: granite de type Guéret et migmatites associées, avec plissement intense et absorption syntectonique, au Nord de Vannes, d'Auray et d'Hennebont.

Des migmatites analogues, granitiques ou pegmatiques, et un peu de granite, certainement lié au précédent, apparaissent aussi dans les replis isoclinaux de la zone couchée méridionale (île d'Arz, île-aux-Moines, côte de Vieux-Ruault et Lageo du Morbihan, côte atlantique de Port-Navallo, plis isoclinaux de la rivière d'Auray).

(*d*) *Granites ou diorites quartzifères à amphibole.*—Des granites et surtout des diorites quartzifères à amphibole ont été décrits, depuis longtemps, dans le Limousin, aussi bien septentrional que méridional. L. de Launay a insisté sur le passage de ces diorites quartzifères au granite normal à biotite et sur leurs relations avec des amphibolites.

Les massifs les plus importants apparaissent dans les zones 7 et 9, près de Confolens, Availles-Limouzine et l'Isle-Jourdain, bordés par le Mésozoïque du Poitou.

De l'autre côté du Poitou, exactement en direction axiale, affleurent dans la zone 9, des diorites

quartzifères à amphibole analogues, qui représentent ici plus nettement des faciès de bordure, endomorphiques, du granite normal à biotite: granite à amphibole de Parthenay-le-Vieux, du Tallud et de Moncoutant, celui-ci non encore signalé.

La liaison de ces granites ou diorites quartzifères à amphibole de l'Armorique vendéenne et du Limousin, d'ailleurs notée déjà par G. Mathieu, est évidente.

Peut-être n'est-ce pas, au sens strict, une liaison magmatique, mais un mode de formation analogue, par variation du granite normal, en raison de l'absorption du même matériel amphibolique.

IV. CONCLUSIONS

(1) Des recherches récentes m'ont permis de distinguer dans le Limousin septentrional deux anticlinaux fondamentaux, l'anticlinal de Rochechouart-Limoges-Bourganeuf, qui, au delà de la faille d'Argentat, se prolonge probablement, après une brusque incurvation, dans la zone granulitique du plateau de Millevaches et dans la grande virgation de la région médiane du Massif Central, et l'anticlinal du Dorat et de Magnac-Laval, prolongement de l'anticlinal du granite de Guéret.

J'ai observé, au Sud de cet anticlinal, une zone de plis isoclinaux déversés vers le Sud, probablement en partie zone de racines, d'où les plis ont déferlé vers le Sud, et, au Sud de l'anticlinal de Rochechouart, une série d'anticlinaux et synclinaux à peu près symétriques, où apparaissent, en divers points, les traces de mouvements tangentiels antérieurs à ce plissement secondaire, et dans la partie Ouest, au Sud de Rochechouart, des plis isoclinaux, poussés vers le Sud.

(2) Dans l'Armorique méridionale, j'ai observé, au Sud de l'Armorique classique, de style à peu près jurassien, le passage du Paléozoïque daté (Cambrien au Gothlandien) à des formations épimétamorphiques, puis nettement cristallophylliennes, et une structure orogénique complexe.

Le fait nouveau le plus important consiste dans l'orientation des poussées apparentes vers le Sud. J'ai distingué des zones de plis isoclinaux redressés, parfois avec absorption magmatique syntectonique, et des anticlinaux intermédiaires, assez larges, tout au moins dans la partie orientale de l'Armorique, enfin, au sud d'un anticlinal fondamental, une zone couchée, où apparaissent clairement les traces de mouvements tangentiels et même, probablement, une véritable nappe, dans la presqu'île de Rhuis.

(3) La plus grande partie de l'Armorique sédimentaire classique échappe axialement au Massif Central et se prolonge sous le Mésozoïque et le Cénozoïque du bassin de Paris. La partie méridionale du Massif Central et, pour une part, la région médiane échappent axialement à l'Armorique, parce que leur prolongement est masqué par le Mésozoïque jusqu'à l'Atlantique.

Pour les parties qui se correspondent, dont la largeur varie de 100 à 130 km., apparaît une liaison stratigraphique, structurale et magmatique, souvent très précise.

Le Cristallophyllien, paléozoïque et peut-être en partie précambrien, de l'Armorique méridionale a un prolongement certain dans le Limousin septentrional et méridional, où existe d'ailleurs, interstratifié dans des micaschistes et amphibolites, un calcaire à entroques, probablement silurien.

Les anticlinaux fondamentaux, les zones de plis isoclinaux déversés vers le Sud, en partie zones de racines, enfin les zones couchées, où apparaissent les traces de mouvements tangentiels, peuvent être raccordés, de part et d'autre du Poitou, et suivis jusqu'à l'extrémité occidentale de l'Armorique.

Enfin la liaison magmatique et souvent aussi axiale peut être établie avec certitude pour les granites à deux micas (granulites), pour les orthogneiss ou gneiss d'injection laminés et recristallisés, pour des granites calco-alcalins, syntectoniques, associés à des migmatites, du type du granite de Guéret, enfin pour des diorites quartzifères à amphibole.

(4) Ces raccords entraînent ou confirment des conclusions importantes pour les deux régions: pour l'Armorique méridionale, importance des poussées vers le Sud, importance des mouvements tangentiels, plus nets d'ailleurs ici que dans le Limousin, mais dont les régions médiane et orientale du Massif Central nous offrent des exemples de plus grande envergure, pour le Limousin et, par continuité pour son prolongement axial, âge paléozoïque du métamorphisme dans le Limousin septentrional comme dans le Limousin méridional, où il est établi directement, âge certainement hercynien de l'orogenèse essentielle, d'après ce qui peut être établi en Armorique, âge certainement

carbonifère des granulites du Massif Central et presque certainement carbonifère des gneiss d'injection et orthogneiss, âge probablement carbonifère, mais antéviséen, des granites profonds calco-alcalins de Magnac-Laval et du Dorat, de Guéret et, par continuité, du Forez et des Cévennes, en accord avec les conclusions probables que j'avais formulées directement dans le Massif Central.

(5) La continuité des structures essentielles, socle précambrien et plis de couverture au Nord, zones de plis serrés, avec métamorphisme du Paléozoïque et poussées apparentes vers le Sud, zone cristallophyllienne couchée, en partie paléozoïque, où existent soit de véritables nappes, soit au moins les traces de mouvements tangentiels, apparaît ainsi, de manière très probable, sur 800 km., depuis l'extrémité occidentale de l'Armorique jusqu'à la bordure est du Massif Central.

Comme je l'avais signalé déjà en 1929, 1933 et 1934, une structure analogue apparaît en Bohême, du domaine moldanubien aux nappes moraviques.

On peut évoquer ainsi, sinon avec certitude, du moins avec plus de force que dans mon hypothèse de 1929, la continuité de ces grandes structures dans toute la chaîne hercynienne d'Europe sur 1.600 km.

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APERÇU DE NOS CONNAISSANCES SUR LA GÉOLOGIE DE L'INDOCHINE EN 1948

Par J. FROMAGET

France

RÉSUMÉ

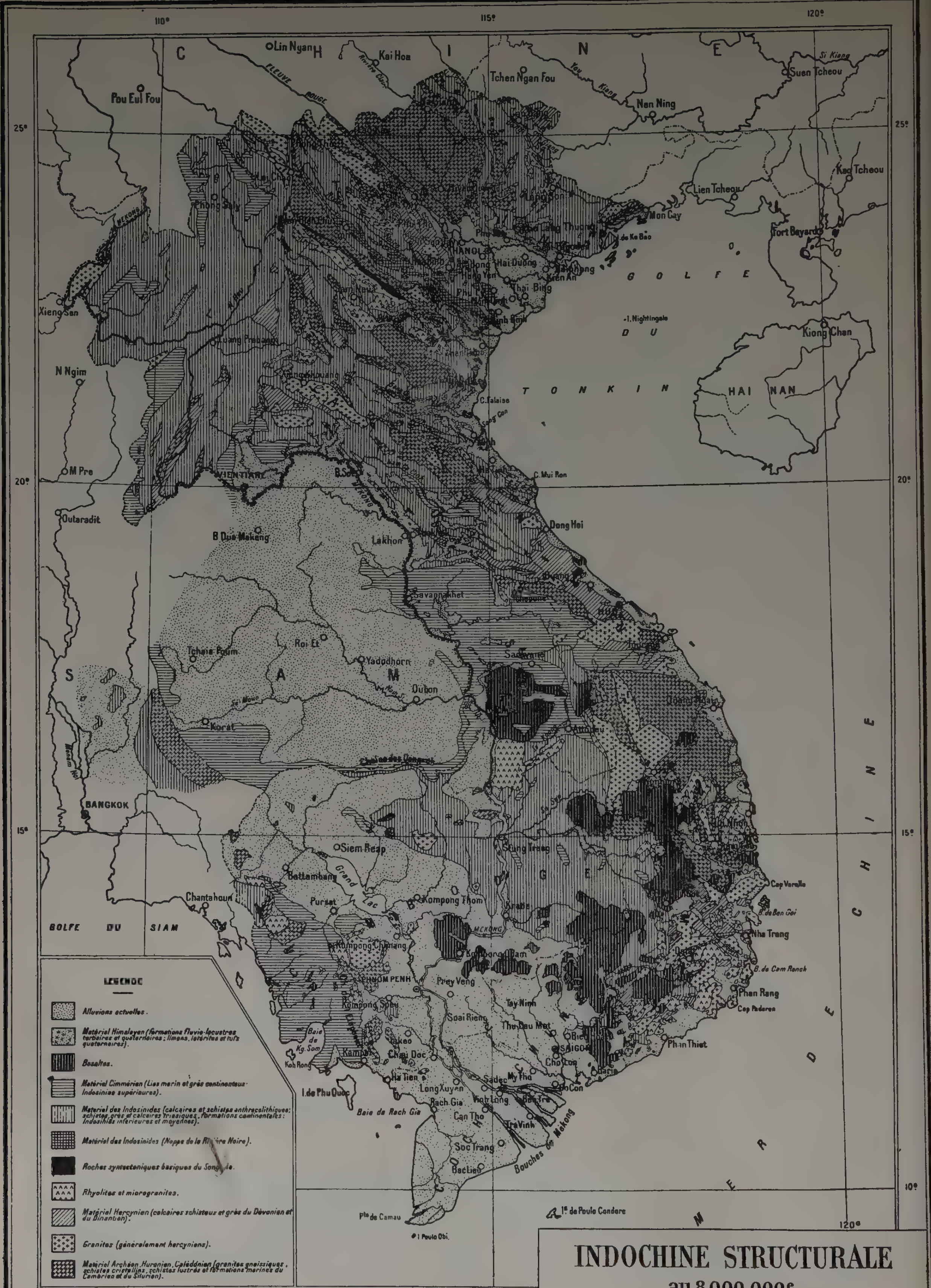
Au cours de la dernière décade, l'activité du Service Géologique de l'Indochine s'est considérablement ralentie du fait des évènements qui ont entraîné la réduction du personnel et même l'arrêt des recherches à partir du 9 mars 1945. Le présent exposé diffère donc peu de celui qui a été présenté au Congrès de Moscou. Du point de vue stratigraphique, les Matériels reconnus alors ont été cependant complétés sur certains points. Les plus vieux Matériels (Archéen, Huronien et Calédonien) ont été identifiés dans les séries métamorphiques du Centre-Annam; dans le Nord de l'Indochine, l'Ordovicien marin fossilifère a, en outre, été découvert au Tran Ninh (Laos). Parmi ces matériels, les formations marines ne contiennent des restes organisés qu'à partir du Cambrien, particulièrement développé à l'extrémité septentrionale du Tonkin. Dans le Sud de l'Indochine, cet étage n'est connu qu'en un point du Cambodge par des quartzites à trilobites. L'Ordovicien fossilifère n'a encore été signalé qu'au Tonkin et dans le Nord-Annam où il existe seul, alors que dans la Chaîne Annamitique il est parfois surmonté par le Gothlandien. Le Matériel Hercynien n'est encore fossilifère que dans l'Indochine du Nord; au Sud de la Sékong ses dépôts sont complètement métamorphisés. Les successions, qu'on observe au Tonkin et dans la Chaîne Annamitique, sont assez complètes dans le Dévonien, mais le Tournaisien n'existe que dans cette dernière région. Parmi les Matériels qui viennent au-dessus (Indosinien, Cimmérien et Himalayen), c'est le Cimmérien qui a fourni le plus de renseignements intéressants: ceux-ci concernent le Lias de la vallée de la Sékong et du Cambodge où sont connus maintenant tous les étages de ce système avec d'assez nombreux fossiles. Dans les autres Matériels, on ajoute à présent, d'une part, une gouttière de Carnien dans le Haut-Laos et un petit affleurement de Norien dans le Sud-Annam et, d'autre part, de nouveaux gisements de Quaternaire à Orangs au Laos et au Tonkin. Dans cette dernière région, des dents d'Hominiens ont également été recueillies. Tels quels, ces Matériels Indosino-Himalayens ne présentent de belles séries marines que dans l'Anthracolithique, le Trias et le Lias; le Jurassique moyen et supérieur parait manquer ou est continental; quant au Crétacé, au Tertiaire et au Quaternaire, ils ne comprennent que des sédiments continentaux. Au point de vue paléogéographique et tectonique, le plan donné précédemment n'a pas été modifié. La répartition des sédiments marins et des roches éruptives profondes suivant des alignements disposés en arcs concentriques regardant vers le Sud-Est et se réunissant dans la Chine du Sud à l'Est du Tibet, montrent que l'Indochine a été affectée par des plissements qui, depuis les temps les plus reculés, ont conservé la même disposition générale. Dans ce plan, l'Indochine appartient à l'aile droite forcée et actuellement figée d'une virgation qui s'étale plus largement dans les guirlandes du Pacifique. L'un de ses éléments, Bornéo, ne serait qu'une partie de l'Indochine qui se serait détachée au Quaternaire avant de dériver ensuite vers le Sud, le long de sa surface de rupture.

Enfin, du point de vue minier, nos connaissances se sont enrichies par la découverte de cuivre, d'étain, de bauxite et de charbon gras. Certains gisements de ces substances minérales paraissent appelés à un grand avenir.

Au moment où, après 50 années d'existence, le Service Géologique de l'Indochine a interrompu ses travaux pour un temps qu'on voudrait espérer assez court, ayant perdu, pendant la tourmente, ses documents, ses publications et tout son matériel scientifique, il n'est pas inutile de refaire le point sur l'état actuel de nos connaissances concernant la géologie de cette partie si intéressante de l'Extrême-Orient méridional.

Au cours de la dernière décade, l'avancement des travaux s'est beaucoup ressenti de l'état de guerre qui amena tout d'abord la réduction du nombre des géologues, puis enfin la cessation complète des recherches sur le terrain le 9 mars 1945.

Pour ces raisons, mon exposé ne saurait donc être très différent de celui que j'ai donné à Moscou en 1937 au cours du précédent Congrès Géologique International et que j'ai repris en 1941 dans une synthèse plus complète à laquelle il sera bon de se reporter pour plus de détails. Les retouches apportées au plan fourni au XVIIe Congrès ne le modifient en rien; elles ne font que le confirmer en le précisant


INDOCHINE STRUCTURALE
au 8.000.000e
LEGENDE
Alluvions actuelles.
Matériel Himalayen (formations fluvio-lacustres tourbeuses et quaternaires ; limons, latérites et tufs quaternaires).
Basaltes.
Matériel Cimmérien (Lias marin et grès continentaux : Indosinias supérieures).
Matériel des Indosinides (calcaires et schistes anthracolithiques ; schistes, grès et calcaires triasiques, formations continentales : Indosinias inférieures et moyennes).
Matériel des Indosinides (Nappe de la Rivière Noire).
Roches syntectoniques basiques du Song ..e.
Rhyolites et microgranites.
Matériel Hercynien (calcaires schisteux et grès du Dévonien et du Dinantien).
Granites (généralement hercyniens).
Matériel Archéen, Huronien, Calédonien (granites gneissiques, schistes cristallins, schistes lustrés et formations marines du Cambrien et du Silurien).
110°
115°
120°
25°
20°
15°
10°
CHINE
SIAM
GOLFE DU TONKIN
MER DE CHINE
GOLFE DU SIAM
HAI NAN
Lin Ngan
Kai Hoa
Tchen Ngan Fou
Nan Ning
Suen Tcheou
Si Kiang
Pou Eul Fou
Kao Tcheou
Lien Tcheou
Fort Bayard
Mon Cay
Kiong Chan
I. Nightingale
FLEUVE ROUGE
MEKONG
Phong Saly
Lang Son
HANOI
Hai Duong
Thai Binh
Kien An
Xieng Sen
Luang Prabang
N Ngim
M Pre
Outaradit
VIENTIANE
C. Falaise
C. Mui Ron
B. Dua Makeng
Lakhon
Dong Hoi
Savannakhet
Tchaia Poum
Roi Et
Yadodhorn
Oubon
Korat
Menam
BANGKOK
Siem Reap
Battambang
Grand Lac
Pursat
Kompong Thom
Stung Treng
Kratie
Chantaboun
Kompong Chnang
Kompong Cham
PHNOM PENH
Prey Veng
Tay Ninh
Kompong Speu
Soai Rieng
Thu Dau Mot
SAIGON
Cholon
Baie de Kg. Som
Koh Rong
Kampot
Takeo
Chau Doc
Ha Tien
I. de Phu Quoc
Long Xuyen
Rach Gia
Baie de Rach Gia
Sadec
My Tho
Vinh Long
Ben Tre
Can Tho
Tra Vinh
Soc Trang
Bac Lieu
Bouches du Mekong
Pte de Camau
I. Poulo Obi
Ie de Poulo Condore
Quang Ngai
Cap Varella
B. de Ban Goi
Nha Trang
B. de Cam Ranh
Phan Rang
Cap Padaran
Phan Thiet
FIG. I

et, tout en concernant surtout la stratigraphie paléontologique, elles fournissent un appoint important à nos connaissances sur la tectonique indosino-himalayenne et, en particulier, sur ses dernières phases. Ce complément d'informations est dû à MM. F. Bonelli, J. H. Hoffet, E. Saurin et moi-même. Au point de vue géographique, il intéresse le Haut et le Bas-Laos, le Nord et le Centre-Annam, le Cambodge septentrional et oriental.

Pour être aussi bref que possible, le présent compte-rendu comprendra deux parties principales: l'une, stratigraphique et structurale en même temps, et l'autre, paléogéographique et tectonique, celle-ci montrera l'évolution de la péninsule indochinoise suivant une cinétique qui est restée la même pendant toute la durée des temps géologiques, depuis l'Algonkien.

Une conclusion de quelques lignes situera les problèmes tectoniques dans leur cadre asiatique.

Enfin, dans un court paragraphe je donnerai quelques renseignements sur les possibilités minières qu'ont laissé entrevoir les recherches effectuées par le Service Géologique depuis 1939.

I. LA STRATIGRAPHIE STRUCTURALE

La classification des formations géologiques en Matériels tectoniques simplifie la question en la rendant plus conforme à ce que l'on observe sur le terrain. Elle permet aussi de situer dans le temps et dans l'espace les formations azoïques de tous âges, ainsi que les séries éruptives. En Indochine, on a pu séparer ainsi un très vieux Matériel Archéen d'autres Matériels très anciens comme le Matériel Huronien, également cristallophyllien, ou beaucoup moins métamorphisé comme le Matériel Calédonien avec lequel apparaissent les fossiles. Au dessus, les discordances, les lacunes et aussi les faciès ont facilité cette séparation jusqu'aux Matériels les plus récents, lesquels, dans l'ensemble, ne sont marins que localement jusqu'au Lias supérieur seulement, et continentaux sur toute la péninsule à partir du Jurassique moyen.

Le Matériel Archéen a dû constituer le bâti profond de l'Indochine, mais il ne forme des affleurements de quelque importance que dans l'Indochine du Nord où il comprend dans le Nord du Tonkin et la Cordillère Annamitique quelques schistes cristallins d'origine sédimentaire et de plus nombreux orthogneiss et ortho-micaschistes à structure oeillée, dans lesquels aucun minéral n'est exclusif de l'origine strictement ignée de ces roches. Ce sont des roches généralement très acides contenant fréquemment grenat, tourmaline, spinelle, sillimanite et apatite, avec plus rares zircon et sphène; amphiboles et pyroxènes exceptionnels, à moins que ces minéraux ne forment la plus grande partie des roches.

Dans le Sud de l'Indochine, la constitution de ce Matériel est sensiblement la même, mais il est plus alcalin.

Le Matériel Huronien (Algonkien) n'est bien connu que dans le Nord du Tonkin et aussi dans le Centre-Annam (E. Saurin). On a pu y distinguer deux séries: 1°, une série éruptive profonde avec orthogneiss et micaschistes noduleux acides ou calco-alcalins avec mylonites, accompagnée de granites gneissiques, parfois alcalins à pyroxène et amphibole sodiques. 2°, une série sédimentaire et volcanique comportant de bas en haut, des schistes micacés graphiteux, des para-amphibolites et des schistes amphiboliques avec ortho-amphibolites, enfin des quartzites à deux micas, des cipolins et des andésites métamorphisées.

Le Matériel Calédonien (Cambrien, Silurien) n'a encore été identifié qu'en un petit nombre de points. Il est quelquefois fossilifère. Lorsqu'il est très métamorphisé, ce qui est le cas le plus fréquent, il comprend dans le Nord du Tonkin une épaisse série de schistes souvent gréseux, lustrés, chloriteux et micacés passant par sa base sur la rive droite du Fleuve Rouge à la Série de Cocxan qui est constituée par des amphibolites avec schistes et des chloritoschistes, au-dessus desquels viennent des cipolins, puis enfin des calcschistes, des quartzites et des schistes, le tout plus ou moins graphiteux et micacé avec apatite grenue disposée souvent en couches épaisses.

Dans la région de Dalat (Sud-Annam) ce Matériel est représenté par des quartzites micacés et des andésites métamorphisées.

Toutes ces formations sont continentales et probablement littorales (partie de la Série de Cocxan).

Les sédiments marins sont plus rares: le Cambrien n'est connu qu'en deux points, à l'extrême Nord du Tonkin, à Chang Poung, où il est calcaire, schisteux et gréseux, et très riche en trilobites, puis au Cambodge septentrional où ses quartzites horizontaux ont donné un de ces crustacés.

L'Ordovicien est un peu plus répandu, on ne le connaît cependant encore que dans l'Indochine du Nord: dans le Tonkin septentrional, il est représenté par des formations lagunaires reposant sur le Cambrien marin de Chang Poung et par des schistes à graptolites et trilobites dans le Bac Son. Dans le Nord-Annam, il est constitué par des schistes et quartzites à grands asaphidés. A l'Ouest de Napé (Laos) il comprend des schistes et des grès à trilobites comparables à ceux du Nord-Annam. Enfin, à la bordure Nord du Tran Ninh (Laos) se voient des schistes satinés à *Trinucleus* cf. *ornatus* (J. Fromaget).

Quant au Gothlandien, il est encore plus rare, ses affleurements indiquent des dépôts de mer un peu moins profonde qu'à l'Ordovicien. Ils sont situés en deux points de la Chaîne Annamitique: à l'Ouest de Napé, où ils reposent normalement sur l'Ordovicien; ce sont alors des schistes gréseux à *Calymene* et brachiopodes; et à Muong Khao au Nord de Ban Ban (Tran Ninh), où il est représenté par des grès schisteux à *Encrinurus*. Dans la Chaîne Annamitique septentrionale, près de Muong Son, des grès schisteux à *Calymene* et brachiopodes font le passage au Dévonien.

Le Matériel Hercynien (Dévonien-Carbonifère inférieur jusqu'au Namurien) montre également les témoins les plus étendus et les mieux caractérisés de ses formations marines dans l'Indochine du Nord. Dans le Sud de l'Indochine, ces terrains auraient été en majeure partie digérés par les granites hercyniens; ils y sont recouverts par des sédiments ou par des roches éruptives plus récentes.

Aucune formation volcanique ou intrusive, les granites mis à part, n'est connue dans ce Matériel.

Ses faciès marins sont schisteux, calcaires et moins souvent gréseux dans le Dévonien; dans le Carbonifère inférieur, on observe surtout des calcaires, des schistes, des grès schisteux et aussi localement de grandes épaisseurs de lydiennes ou quelques poudingues.

Les successions observées dans les dépressions marines hercyniennes sont les suivantes: dans le Nord et le Nordest du Tonkin (Dong Quan, Caobang) le Dévonien comprend un peu de Coblentzien à *Chonetes zeilli* puis, en transgression, de l'Eifélien à *Spirifer speciosus*, du Givetien à *Stringocephalus burtini* et du Frasnien à *Spirifer ziczac*. Latéralement, ces formations passent à des sédiments littoraux de l'Eifélien à Stromatopores et *Orthonychia*, puis à des grès sans fossiles.

Le Carbonifère inférieur n'est pas connu dans cette région.

Dans l'Est du Tonkin, le Dévonien et le Carbonifère inférieur sont représentés par du Givetien ou du Frasnien à *Spirifer* cf. *ziczac* et par du Dinantien à *Spirifer angulicostatus*.

Dans le Nord-Annam, la série primaire du Bas Thanh Hoa de Ch. Jacob, contient à sa partie supérieure du Dévonien moyen, schisteux à *Spirifer speciosus* et calcaire à Anthozoaires.

C'est sans doute aux dépôts d'une dépression autrefois située dans la vallée du Song Ma et prolongeant au Nordouest la série du Bas Thanh Hoa qu'appartient le Dévonien charrié de la Nappe de la Rivière Noire dans laquelle on connaît: du Dévonien inférieur marneux à *Cypricardella*, de l'Eifélien schisteux à *Spirifer speciosus* et des calcaires givetiens et probablement frasniens à *Spirifer pachyrhynchus*. Le Carbonifère inférieur manque.

Mais c'est dans la Cordillère Annamitique que les formations hercyniennes atteignent leur plus beau développement. Les successions fossilifères n'y sont cependant qu'exceptionnellement complètes, mais les lacunes sont dues autant à l'absence de fossiles qu'aux plissements et charriages. Dans le Dévonien, l'horizon le plus bas est le Coblentzien avec des grès et des calcaires à *Spirifer carinatus*, puis viennent l'Eifélien schisteux à *Calceola sandalina* ou calcaire à *Spirifer curvatus*, le Givetien schisteux à *Styliola clavulus* et calcaire à *Stringocephalus burtini* et le Dévonien supérieur à *Spirifer pachyrhynchus*, à *Spirifer ziczac* ou bien encore à *Leptodesma jacobi*. Le Tournaisien qui vient audessus est représenté par des schistes gréseux à brachiopodes et par des brèches dévalantes supportant en discordance angulaire le Viséen qui prend un beau développement avec des calcaires fétides à *Productus giganteus*, des calcaires et schistes à *Nomismoceras* et *Neuropteris*, des schistes à *Phillipsia*

et brachiopodes et des schistes et lydiennes à radiolaires. La série hercynienne se termine par des schistes ou des calcaires à *Daraelites praecursor* du Namurien et par des grès et poudingues sans fossiles. Aux environs de Pac Sang, au Sud du Haut-Laos, des calcaires à débris de trilobites et brachiopodes indiquent l'éxistence du Dévonien.

Les dépôts fossilifères les plus méridionaux proviennent de la vallée de la Sékong (Bas-Laos). Ce sont principalement des grauwackes à *Orthotetes umbraculum.*

Dans le Sud-Annam, les sédiments attribués au Matériel Hercynien sont des schistes et des lydiennes métamorphisés et sans traces de fossiles.

Des masses considérables de granites intrusifs métamorphisent tout ce Matériel qui est séparé du Matériel suivant par une discordance observable partout en Indochine. La distribution de ces granites est particulièrement suggestive; elle met en relief avec la plus grande netteté le plan de l'édifice hercynien.

Dans l'Indochine du Nord, leurs affleurements suivent les directions des dépressions marines (synclinaux ou détroits); ils sont de ce fait plus étendus dans les régions sédimentaires hercyniennes que dans les régions cristallines où ils sont réduits à des culots qui peuvent être considérés alors comme la partie profonde de batholites enlevés par l'érosion.

Au Sud de Tourane, certains massifs granitiques sont orientés du Nord au Sud suivant une direction aberrante sur le plan général.

Par ailleurs, en de nombreux points de l'Indochine, aucun sédiment ne se place entre les granites et leur couverture de microgranites et de rhyolites tout comme s'il y avait eu passage progressif des unes aux autres de ces roches. C'est en particulier le cas des massifs du Bou Ginh au Tonkin, du P'ou San au Tran Ninh et de la Porte d'Annam. Dans la partie méridionale du Centre-Annam, les alignements de rhyolites affleurant au milieu du vieux Cristallin et allongés du Nord au Sud comme les granites hercyniens pourraient représenter une semblable disposition et se relier à des granites à une assez faible profondeur. J'insiste sur cette particularité des gisements de toutes ces roches acides dans le Centre-Annam, en raison de l'importance qu'on pourra en déduire au point de vue de la dislocation du Môle Cambodge-Bornéo au cours des périodes géologiques qui vont suivre.

Le Matériel des Indosinides. Ce Matériel est nettement discordant sur l'édifice hercynien et n'a jamais été métamorphisé par ses granites. Ses différents éléments peuvent être discordants entre eux. Il comprend des sédiments marins disposés suivant le plan des grandes dépressions hercyniennes en continuel mouvement, des sédiments continentaux contenant des épisodes marins, des roches éruptives intrusives et des intercalations de laves surtout acides et neutres. Ces dernières formations constituent les parties inférieures et moyennes des " Indosinias " : puissante série continentale qui correspond à la totalité du Matériel Indosino-Himalayen. Les formations marines, y compris celles qui sont intercalées dans les précédentes appartiennent à l'Anthracolithique moyen et supérieur et au Trias.

Parmi celles-ci les premières sont essentiellement néritiques et calcaires, riches en foraminifères, les secondes sont surtout bathyales et schisteuses avec ammonites, et aussi néritiques et gréseuses; on y trouve encore d'importantes séries de poudingues transgressifs et des sédiments lagunaires. La série anthracolithique n'est à peu près complète que dans la Cordillère Annamitique. On y connaît, en effet, du Moscovien à *Neofusulinella bocki*, plusieurs niveaux de l'Ouralien à *Schwagerina princeps*, de l'Artinskien schisteux à *Meddlicotia artiensis*, du Permien calcaire avec *Neoschwagerina craticulifera* à la base et *Sumatrina longissima* dans les horizons supérieurs. Dans le reste de l'Indochine l'Anthracolithique n'a jamais été au complet; il forme des intercalations à l'intérieur de la série basale des " Indosinias." C'est ainsi que le Moscovien et l'Ouralien inférieur ne sont connus que dans le Nord et l'Est du Tonkin (Dong Quan, Lung Xung, Kim Hi, baie d'Along, etc.) et au Sud de Luang Prabang (Ta Dua, Muong Heup); l'Ouralien supérieur et une partie du Permien dans le Bac Son, le Haut Tonkin occidental et la Nappe neotriasique de la Rivière Noire, à l'Ouest du Haut-Laos, à l'Ouest du plateau de Korat (Siam), au Tran Ninh et dans la région de Saravane (Bas-Laos). Le Permien supérieur constitue, par ailleurs, presque tous les affleurements calcaires déposés le long du Mékong

dans la région de Luang Prabang et à l'Ouest du Cambodge, en passant par la rive gauche du Menam (Siam). (Certaines couches à charbon de Luang Prabang pourraient indiquer l'horizon terminal du Permien, c'est probablement de ce niveau que provient le crâne de Dicynodonte, recueilli dans les couches rouges du Trias, qui l'auraient remanié). Enfin, quelques îlots de calcaires dont l'âge n'a encore pu être précisé se trouvent à l'Ouest de la vallée du Nam Beng et sur le Nam Ou dans le Haut-Laos.

La fin du Permien et le début du Trias paraissent correspondre à une période d'émersion; les plus anciens sédiments werféniens connus n'occupent plus que de petits emplacements dans la région de Langson (calcaires et calcschistes à *Columbites* ou à *Meekoceras*) et au Sud de Luang Prabang (schistes à *Xenodiscus Salomonii*). Au Trias moyen, les sédiments marins sont un peu plus répandus: le Virglorien est connu dans la région de Langson (Tonkin) par *Monophylites suessi*, dans le Nghe An (Nord-Annam) par une riche faune à *Norites gondola*; en deux points de la province de Sam Neua (Laos) par *Ceratites trinodosus* et *C. samneuaensis*, enfin au Cambodge Nord-oriental, d'où proviennent, d'une part, *Balatonites zitteli* et, d'autre part, *Ceratites*, cf. *trinodosus*. Le Ladinien est moins développé, il n'a été trouvé que dans le S. du Tonkin où il a fourni *Trachyceras villanovae* en un point et *Protrachyceras annamense* ailleurs. C'est avec le Carnien que le Trias marin atteignit son maximum d'extension et de profondeur. Ses dépôts ont été observés dans toutes les dépressions de cette époque; aux environs de Langson avec *Paratropites phoebus*, en différents lieux du Tonkin occidental avec *Discotropites plinii*, *Tropites phoenix*, *Juvavites tonkinensis*, dans la région de Luang Prabang avec *Acanthinites excelsus*, dans la vallée du Nam Beng (E. Saurin) avec *Discotropites sandlingensis*, enfin, au Cambodge oriental (E. Saurin) avec *Discotropites sp.*, *Halobia*, *Hauerites rarestriatus*. En outre, des sédiments lagunaires situés en marge du Carnien marin contiennent notamment *Anodontophera munsteri* dans le Haut-Laos et au Cambodge oriental. Le Norien est transgressif sur presque toute la surface de l'Indochine et presque toujours discordant. Il est constitué en grande partie par des sédiments continentaux et lagunaires avec ou sans sel et charbon et hypothétiquement avec gypse qui forment la partie moyenne des "Indosinias." Ses dépôts marins beaucoup plus restreints sont néritiques ou littoraux et, dans ce cas, avec charbon; ils se terminent souvent par des couches lagunaires. Dans l'Indochine du Nord, ils sont localisés aux environs de Contagne (Haut-Mékong), de Luang Prabang et de Saniaboury (Haut-Laos) à la ceinture du P'ou Huat (Nord-Annam et Laos Nord-oriental), dans le Nord-Est de la province de Vinh (Nord-Annam), dans la basse Rivière Noire et au Sud du Dong Trieu (Tonkin). Les dépressions où se sont formés ces sédiments marins alimentaient des lagunes dont les dépôts salifères de Tourakhom (Haut-Laos), du Siam, du moyen et du Bas-Laos, de même que ceux du sillon Lu (Haut-Laos septentrional) et de la rive droite de la haute Rivière Noire sont les témoins. Les faciès et les faunes noriennes sont assez variés: calcaires siliceux à ammonites, *Tibetites*, et brachiopodes, calcaires schisteux à *Placites polydactylus*, grès à *Myophorya emmerichii*, schistes gréseux à *Protocardia contusa* du Haut-Laos, grès schisteux avec ou sans charbon à *Burmesia lirata*, *Myophoria napengensis* et *Gervilleia praecursor* dans les couches plus élevées du Haut-Mékong, du Tran Ninh, des environs de Dien Bien Phu (Nord-Ouest du Tonkin) et contenant quelques ammonites *Anatibetites*, dans la partie Sud du massif du Fan Si Pan et dans l'Est du Tonkin, enfin calcaires siliceux avec brèches dans la vallée du Song Ca et le Nghe An oriental caractérisés par de nombreuses térébratules (*Aulacothyris inflata*, etc.). Dans l'Indochine du Sud le Norien marin est beaucoup moins développé. Il y est surtout connu au Cambodge (E. Saurin) par des grès à ammonites (*Didymites*) et lamellibranches et par des grès charbonneux à *Cardita aff. buruca*; dans le Sud-Annam (E. Saurin) par les grès littoraux de Hoa Huynh à lamellibranches: *Protocardia subrhaetica*, *Gervilleia praecursor*.

Les dépôts continentaux de cette période présentent un grand intérêt, au point de vue pratique, par le sel, le gypse et surtout par le charbon qu'ils contiennent et dont les gîtes d'importance très variable s'échelonnent depuis le Wesphalien jusqu'au sommet du Norien avec des teneurs en matières volatiles allant de 1 à 2 pour cent dans les anthracites très purs du Dong Trieu (Tonkin) à 27 pour cent dans les charbons gras du Muong Theng (Haut-Tonkin occidental). La partie inférieure de ces formations—Indosinias inférieures—est ante-norienne, c'est la moins riche en charbon, bien que ses gisements

en soient aussi nombreux. Ce sont des grès verts ou bleus, feldspathiques, avec intercalations importantes de roches effusives: andésites, dacites et rhyolites et sporadiquement quelques lentilles de couches marines et aussi quelques poudingues transgressifs. La partie moyenne constitue le Terrain Rouge inférieur et comprend en général deux éléments: l'un versicolore, violet, vert, etc. argileux, autant et plus que gréseux; elle appartient au Carnien supérieur ou à la base du Norien; la partie supérieure surtout rouge, gréseuse et marneuse est norienne. Elle débute souvent par des poudingues gréseux transgressifs. La paléontologie de ces " Indosinias " est assez complète, mais les gisements de fossiles sont peu nombreux et très disséminés. Le Westphalien et le Stéphanien charbonneux ont donné dans les Bas-Laos, *Calamites* aff. *goepperti*, puis *Sigillaria brardi*; le Carbonifère supérieur ou le Permien ont fourni au Nord et à l'Ouest de Vientiane *Asterophyllites longifolius*. Du Permo-Carbonifère et du Trias inférieur et moyen du Haut-Laos proviennent des Carbonicoles, puis *Gigantopteris nicotinae-foliae*, *Schizoneura gondwanensis* et enfin *Clathropteris*. Dans le Nord-Annam, des couches charbonneuses vraisemblablement permiennes contiennent *Gigantopteris sp*. Le Norien est généralement charbonneux et fossilifère en de nombreux points: Phong Saly (Haut-Laos), Phan Mé, Hong Hay et Phu Nho Quan (Tonkin), Halinh et Nong Son (Nord et Centre-Annam), enfin O'Kombor dans le Cambodge oriental. Il est caractérisé par la flore à *Glossopteris indica* ou par des végétaux qui indiquent des horizons plus ou moins élevés du sommet du Trias supérieur. En quelques points sa partie rouge contient des troncs silicifiés d'*Araucarioxylon* (Bas-Laos, Cambodge) et de plus rares fossiles d'eau douce: *Unio*, dans la basse Rivière Noire. Les *Araucarioxylon* existent aussi dans le Lias.

Le Matériel Cimmérien—Grès supérieurs—qui vient ensuite, appartient principalement aux " Indosinias " supérieures dont les formations sont datées au Lias par des intercalations marines fossilifères et au Crétacé par des fossiles d'eau douce; le Jurassique moyen et supérieur, de même que la plus grande partie du Crétacé n'ont pas encore livré de fossiles, mais la succession continue de la sédimentation paraît indiquer leur présence au moins dans le Bas-Laos, le Siam et le Cambodge-oriental.

Les " Indosinias " supérieures sont transgressives. A l'exclusion des dépôts marins qui sont schisteux ou calcaires, ce sont surtout des grès continentaux blancs ou rouges, avec lits de galets de quartz et aussi bancs d'argiles et de marnes rouges; on a admis jusqu'à présent qu'elles contenaient du sel et du gypse dans le Bas-Laos, ce qui n'est pas suffisamment démontré. Ces formations continentales sont représentées par des témoins plus ou moins importants dans le Nord du Haut-Laos, ou recouvrent de très grandes surfaces dans le moyen et le Bas-Laos, le Siam et le Cambodge occidental.

Par contre, les formations marines du Lias ne sont développées que dans la partie orientale de l'Indochine du Sud et la disposition de ces dernières se fait suivant un même alignement Nord-Sud depuis l'arrière-pays de Tourane jusqu'en Cochinchine en passant par la vallée de la Sékong. Un affleurement se trouve, en outre, sur la côte du Sud-Annam où sont signalés quelques lamellibranches de cet âge à Phu-Yen. La répartition des fossiles liasiques dans la dépression principale ou à ses abords dans le golfe du Cambodge a permis d'identifier de l'Hettangien à *Aegoceras longipontinum* à Huu Nien (Sudouest de Tourane), du Sinémurien à *Gryphea arcuata*, au Cambodge septentrional, du Charmouthien à *Polymorphites jamesoni* dans la vallée de la Sékong et à la bordure Ouest du Kontum, enfin du Toarcien à Ban Don (Darlac), dans la vallée de la Sékong, dans la province de Pleiku et dans les environs de Saïgon où il contient partout de nombreux lamellibranches avec quelques ammonites dont *Harpoceras* cf. *quadratum* au Darlac et en Cochinchine; dans la vallée de la Sékong, certains lamellibranches semblent aussi indiquer l'Aalénien. Les dépôts fossilifères du Crétacé appartiennent à la partie inférieure du Sénonien; ce sont des grès à lamellibranches (*Unio*, *Hoffettrigonia*) et grands sauriens (*Mandchurosaurus* et *Titanosaurus*). Les gisements en sont tous situés dans le Bas-Laos entre Savannakhet et Tchepone (J. H. Hoffet).

Le Matériel Himalayen est surtout continental: poudingues, grès, schistes, marnes avec ou sans lignites et coulées basaltiques; celles-ci sont abondantes dans l'Indochine du Sud et, en particulier, dans sa partie orientale. Les seuls sédiments marins sont de rares dépôts de plages d'âges quaternaire (?) et récent; ils ne sont connus que dans l'Indochine du Nord, dans le Sud-Annam et la Cochinchine.

Leurs basaltes et les produits d'altération (latérites) mis à part, aucune de ces formations n'est très étendue. Les dépôts continentaux se raccordent par endroits à de hauts niveaux. Les plus anciens sont plissés ou basculés et sont disposés au fond des gouttières des grandes vallées: Fleuve Rouge, Song Chay, Rivière Claire, partie inférieure du bassin de lignite de Dong Giao (Tonkin), Nam Beng (Laos). Quelques uns, cependant, forment des crêtes qui peuvent dépasser 1.500 m. d'altitude (Muong Peun-Laos); leur âge est Mio-pliocène, ceux du Nam Beng sont placés par E. Saurin dans le Pliocène inférieur. Dans la Chaîne Annamitique (Muong Peun), des conglomérats ravinent les dépôts précédents et se mettent en relation avec une pénéplaine de 1.000–1.400 m., la pénéplaine du Tran Ninh qui occupe, actuellement, des surfaces considérables; on connaît des témoins du remblaiement qui l'accompagne au Tran Ninh, dans le haut Nam Mu (Tonkin) et à Dalat où cette pénéplaine est à un niveau un peu supérieur (plus de 1.500 m.). Le remblaiement le plus remarquable qui vient ensuite est celui de Ban Ban au Nord-Est du Tran Ninh, il correspond à une pénéplaine de 650–900 m.; ce sont des couches fluvio-lacustres à poissons (*Labeo* et *macrones*) et des poudingues. C'est à ce niveau que paraissent correspondre au Tonkin, les bassins de Cao Bang et de Thatkhé, ainsi que les pénéplaines de Langson et de Loc Binh, affaissés le long d'un accident. C'est à lui, également, qu'appartiendraient, dans le Sud et le Centre-Annam, les argiles à diatomées de Djiring et de Phu Yen et les coulées de basalte transformées en terre rouge qui se tiennent à 1.000 m. d'altitude. En outre, je suis tenté de lui attribuer les 250 m. de marnes lacustres reconnues dans le substratum du delta du Fleuve Rouge entre les cotes—90 et—340. C'est encore à lui qu'on peut rattacher les dépôts des gouttières de Hong Sa, du Nam Ta et du Nam Beng dans le Haut-Laos; ils forment dans la dernière de ces vallées une terrasse à 10–15 m., latéritisée, que E. Saurin considère comme appartenant au Pliocène le plus élevé (Villafranchien). C'est toujours à cette époque qu'il convient d'attribuer la terrasse du grand lac du Cambodge et certaines terrasses sous-basaltiques du Sud et du Centre-Annam. Le quaternaire inférieur est bien daté par ses tufs à mammifères, avec Hominien, Orang et Stegodonte dans la Chaîne Annamitique (Tam Hang et Tam Pa Loï), Stegodonte à Langson, Orang à Minh Lé (Tonkin) et Houei Hoc (Haut-Laos), Hominien et Orang à Thung Lang (Tonkin méridional). Ces dépôts remplissent des fentes et des cavernes situées à différentes altitudes; ils sont toujours plus ou moins latéritisés. Leur horizon le plus ancien correspond à la base du gisement de Tam Hang et le plus récent au gisement de Thung Lang où il est en relation avec un niveau très constant de 50–55 m. au-dessus de la mer. La latéritisation qui modifie le quaternaire inférieur a pour équivalent latéral des formations argileuses rouges à *Tapirus sp.* ainsi que les terres rouges de décomposition des basaltes; elle est, en outre, antérieure aux plus vieux dépôts archéologiques à *Homo faber* et *Tapirus indicus* exceptionnel (Tam Hang) qui ne sont pas plus anciens que le quaternaire le plus élevé. Sous le delta du Tonkin, les marnes du Pliocène vues précédemment supportent 30 m. de graviers à éléments progressivement plus gros de bas en haut, sur lesquels viennent enfin, sur 50 m., les argiles du delta qui montrent quelques traces de latéritisation près de leur base; ce qui place les graviers dans le quaternaire et la formation du delta à l'époque actuelle.

II. LA PALÉOGÉOGRAPHIE ET LA TECTONIQUE

Au cours de l'exposé qui précède on a pu se rendre compte que, d'une façon générale, les sédiments marins occupaient des emplacements allongés en bandes étroites entre des sédiments continentaux ou limités par des massifs cristallins ou cristallophylliens. Reportées sur une carte, on constate de plus que ces bandes suivent deux directions sensiblement orthogonales entre elles, l'une longitudinale, qui est celle des grandes dépressions marines, décrit des arcs concentriques qui vont se raccorder en Indochine du Nord ou en Chine près de la frontière du Nord du Tonkin occidental, l'autre transversale, tronçonne ces arcs; c'est celle des détroits et de certains golfes. Cet arrangement, avec quelques variations de détail, ne devient cependant très net, que depuis le Dévonien; il paraît toutefois avoir été celui des premiers temps géologiques depuis l'Algonkien. La répartition des plus vieux Matériels, si elle était plus aisée à faire, montrerait sans doute qu'à l'Archéen, l'Indochine, de même que les guirlandes insulaires étaient entièrement soudées au bloc asiatique; le tout se morcela

ensuite au sein de la Tethys, en arcs continentaux, progressivement plus nombreux et, peut-être aussi, séparés par des chenaux plus étroits et plus profonds jusqu'à la fin du Trias; ces arcs, à plusieurs reprises, se soudèrent par la suite plus ou moins intimement avant de se réunir, après la fermeture de cette mer mésogéenne, aux deux masses continentales—Gondwanie et Eurasie—qui les enserraient.

La paléogéographie des temps calédoniens montre déjà une belle esquisse de ce plan. On y distingue d'une part, l'existence d'une mer cambrienne et silurienne, le *Géosynclinal himalayen*, bordant le Tonkin au Nord-Est, et d'autre part, une mer silurienne située sensiblement sur l'emplacement de la Cordillère Annamitique, le *Géosynclinal Annamitique*, qui devait se réunir à la précédente dans le Sud de la Chine, formant avec elle deux des branches de la Tethys primitive. Une ou plusieurs autres branches situées plus à l'Ouest, la plus occidentale passant en Birmanie, séparaient complètement l'Indochine de l'Inde péninsulaire. C'est dans des détroits de ce système disjonctif que se seraient déposés les quartzites cambriens à trilobites du Cambodge septentrional et les quartzites à Asaphidés du Thanh Hoa.

A la fin du Silurien, dont les sédiments marins ne sont connus que dans la Chaîne Annamitique, l'Indochine fut progressivement exondée. Ce n'est qu'au début du Dévonien que la mer pénétra à nouveau dans la Péninsule. A ce moment, le plan disjonctif des arcs resta sensiblement le même, mais on y connaît de plus une mer occidentale, le *Géosynclinal du Haut-Laos* et deux dépressions méridionales, le *golfe de la Sékong* et le *détroit Sud-Annamitique* qui occupa tout le Sud-Annam. C'est à cette époque que se dessina d'une façon particulièrement nette, l'arc continental le plus massif du système indochinois, l' " *Indosinia* " appelée par les anciens géologues: *Massif Cambodge-Bornéo*, qui venait se terminer au Nord-Ouest, aux abords du lieu de convergence de Dien Bien Phu, dont

L'Indochine au Devonien

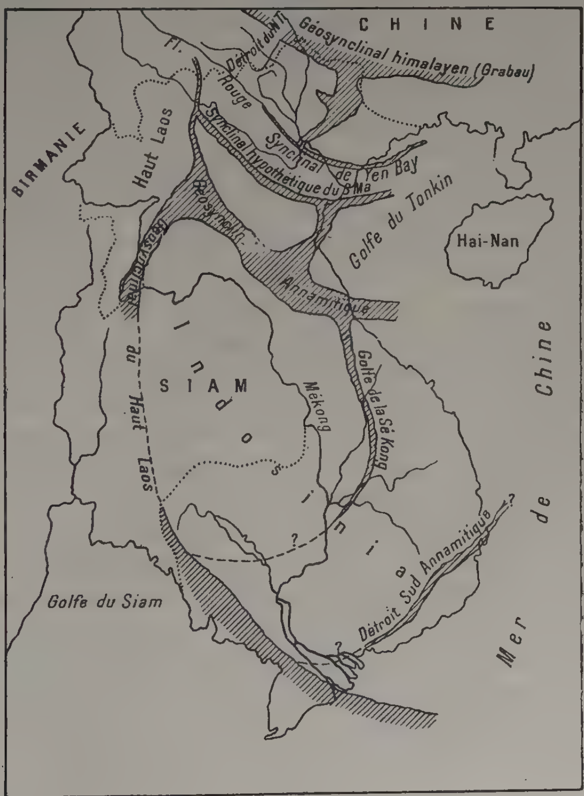


FIG. 2.

l'importance apparaît à nos yeux pour la première fois. Les arcs qui accompagnent l' " Indosinia," plus ou moins morcelés en guirlandes, ont joué de tous temps avec lui, le rôle d'Avant-Pays intercalaires. C'est contre et au-dessus de ces arcs que sont venus déferler les plissements qui se sont succédés en Indochine, au moins depuis l'orogénèse huronienne; mais ce jeu ne nous apparaît avec netteté qu'à partir du Trias. Toutefois, dans la Cordillère Annamitique, l'Edifice Hercynien mieux préservé présente une chaîne principale avec charriages anté et post-viséens et cordon récifal en bordure de l' " Indosinia," son Avant-Pays; l'ensemble fut en fin de compte traversé par des granites intrusifs post-namuriens qui furent, par la suite, minéralisés en étain, sur l'emplacement du bourrelet liminaire.

Après cette orogénèse l'Indochine fut entièrement exondée pour un temps assez bref, puis en majeure partie érodée. En effet, dès le Moscovien moyen ou supérieur, la mer à *Neofusulinella bocki* revint s'installer en marge des trois plus importantes dépressions hercyniennes; géosynclinaux himalayen, annamitique et du Haut-Laos. La seconde de ces dépressions devint même dès cette époque une zone de subsidence où vinrent s'accumuler 1.200 m. de sédiments calcaires à fusulines, correspondant au Carbonifère moyen et supérieur et au Permien. C'est le seul endroit de l'Indochine où une semblable sédimentation post-hercynienne se soit produite. Ailleurs, le sous-sol de la péninsule fut le théâtre d'ondulations qui amenèrent le déplacement constant des mers anthracolithiques dont les dépôts, en général plus plissés que ceux de la Chaîne Annamitique, sont réduits à un ou plusieurs étages de l'Ouralien ou du Permien. Dans le plan général, la distribution de ces dépôts anthracolithiques s'est faite suivant des systèmes d'arcs situés: 1° aux bordures occidentales des Géosynclinaux himalayens et du Haut Laos, au Moscovien supérieur et à l'Ouralien; 2° dans l'important massif du Bac Son qui occupe l'angle Nord-Ouest du point de rencontre du Géosynclinal himalayen et du détroit de Langson, à l'Ouralien supérieur et au Permien; 3° autour de la partie occidentale de l' " Indosinia " limitée à l'Est par une dépression hercynienne dans la vallée de la Sékong, le golfe ou détroit de la Sékong—appelé à prendre une grande importance, beaucoup plus tard, au Lias—au voisinage du Géosynclinal neotriasique du haut Mékong, enfin, dans une dépression hypothétique d'où proviendrait la Nappe de la Rivière Noire à l'Ouralien inférieur et au Permien supérieur; 4° dans une bande morcelée en long qui suit le Géosynclinal du Haut-Laos depuis la région de Luang Prabang jusqu'au Sud du Cambodge, au Permien supérieur. Une nouvelle émersion générale se produisit à la fin du Permien dont le passage au Trias n'est connu encore que dans le détroit de Langson.

À partir du Trias inférieur, le plan des " Indosinides " se dessina progressivement; au Werfénien, les grandes dépressions géosynclinales dépendant de la Tethys ne s'enfoncèrent pas encore très loin à l'intérieur de l'Indochine; l'une d'elles, le Géosynclinal annamitique disparut même définitivement; mais, aussitôt après, dès le Virglorien, le morcellement de l'Indochine en guirlandes ne cessa de se poursuivre jusqu'à la fin du Carnien; l'Indochine formait alors dans le cadre plus grand du Sud-Est de l'Asie, une virgation retenue à son aile droite, relativement libre à son aile gauche, étalée largement à son avant vers le Sud ou le Sud-Est et dont les arcs en général de moins en moins massifs, de plus en plus morcelés en guirlandes, de plus en plus convexes du Nord vers le Sud, furent séparés par des mers profondes qui apportèrent leurs cephalopodes et leurs lamellibranches aux tests minces jusqu'à la bordure orientale du Tibet. Ainsi, jusqu'au Carnien l'action tangentielle s'est opérée sans heurts, elle ne s'est en somme traduite que par des oscillations avec pulsations et cassures accompagnées d'éruptions et suivies de disjonctions. À la fin du Carnien et au cours du Norien, le même phénomène orogénique renversa ses effets; aux disjonctions succéda le rapprochement progressif des éléments disjoints, lequel amena l'expulsion des mers qui tout d'abord réduites à quelques dépressions de moins en moins profondes d'Ouest en Est, n'occupèrent plus à la fin du Norien que des lagunes—dont on a vu la répartition dans la partie stratigraphique de cet exposé—puis produisit en fin de compte, le plissement et le charriage des éléments plastiques (Nappe de la Rivière Noire) et même des arcs entre eux, dont les bords en contact se divisèrent en écailles. Des conglomérats syntectoniques, des roches éruptives basiques (Song Ma) ou alcalines (Nord-Ouest du Tonkin) accompagnèrent ces ultimes phénomènes.

Après le Trias, la mer fut chassée définitivement de l'Indochine du Nord. Il n'en fut pas de même

dans l'Indochine du Sud, où à partir du Lias, des accidents Nord-Sud perpendiculaires aux arcs se mirent à rejouer. On a vu, en effet, que le premier accident de ce genre, le golfe de la Sékong est hercynien; on a vu aussi dans toute cette partie de l'Indochine et en particulier au Nord du Varella, que les affleurements des granites et aussi des rhyolites s'allongeaient en bandes plus ou moins étroites suivant une semblable direction, et que des fractures, longeant le littoral, étaient accompagnées de la mylonitisation des granites, tous ces faits paraissent démontrer que Bornéo, dont la structure géologique de la face Ouest n'est que la réplique, ensevelie en grande partie sous des sédiments plus récents, de celle de la côte orientale du Centre-Annam, tendait déjà à se séparer de l'Indochine. De plus, la présence du Toarcien fossilifère sur les deux faces supposées en connexion de ces deux continents semble indiquer l'existence en ce point d'un golfe ouvert du Nord au Sud, le golfe de Bornéo sur l'emplacement même de la ligne de rupture. Par ailleurs, la disposition des dépôts liasiques dans la dépression de la Sékong allant de l'Arrière-Pays de Tourane à la région de Saïgon montre que celle-ci s'est ouverte

L'Indochine au Carnien
(Unités structurales)

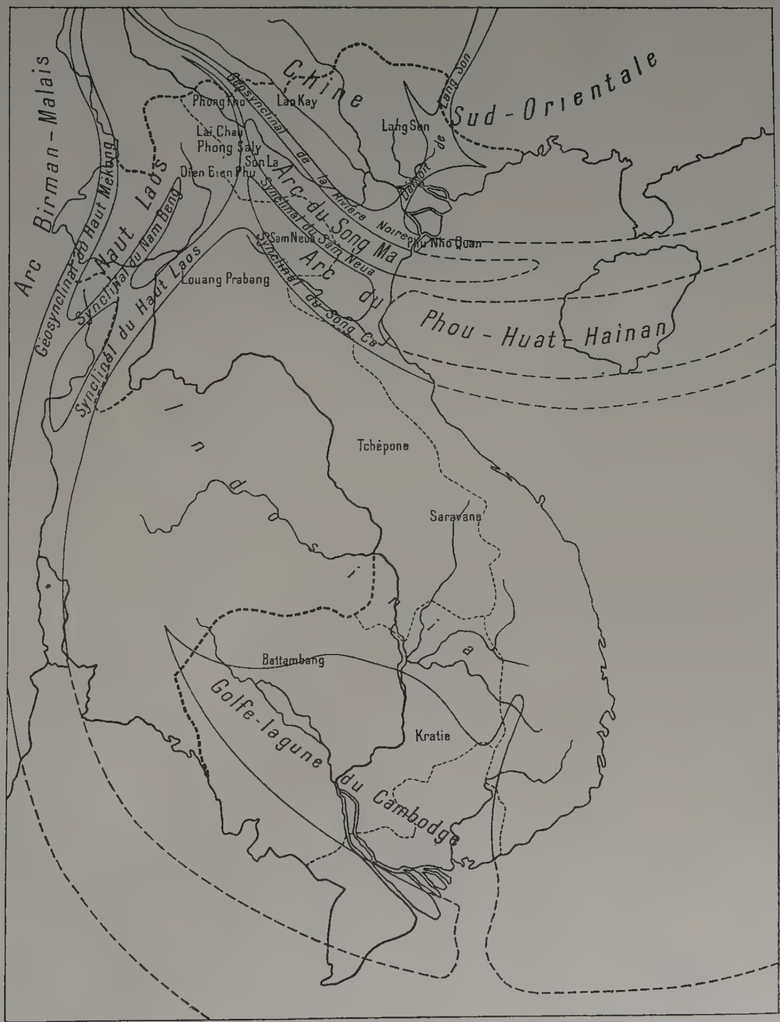


FIG. 3.

progressivement du Nord, vers le Sud, et qu'elle s'est refermée ensuite dans le même sens. La phase terminale de l'extension de la mer liasique correspondit à l'ouverture du golfe de Bornéo et à la plus grande extension du golfe du Cambodge dont elle ne précéda que de peu la fermeture, laquelle se serait faite à l'Aalénien. Les plissements qui ont accompagné ces phénomènes de distension et de compression se seraient donc succédés progressivement du Nord au Sud.

Cette tectonique fait songer à des mouvements de poupe de toute la partie de l'arc de l'Indosinia-Bornéo située à l'Est du détroit de la Sékong; mouvements qui auraient été occasionnés par une tendance à une double rupture de cet arc sous l'influence de tractions en long, développées par l'effort disjonctif. Plus tard, cette tectonique cimérienne n'a pu être observée en Indochine; on sait seulement que le Jurassique supérieur à ammonites existe sur la côte Ouest de Bornéo et qu'au Crétacé supérieur les plages du Centre-Annam septentrional devaient être en relation avec les lacs du Bas-Laos où vivaient de grands Sauropodes.

La dernière phase de plissements, ou phase himalayenne fut peu sensible en Indochine bien que certains de ses effets furent très importants. Ses paroxysmes se placeraient après le Pliocène inférieur et moyen. Postérieurement à eux, on n'enregistre plus que de grandes ondulations disposées en arcs semblablement aux orogénies les plus anciennes. Aux mouvements du Pliocène inférieur nous ne pouvons rattacher pour le moment que les plissements des sédiments d'eau douce du Haut-Laos (Nam Beng) de la Chaîne Annamitique septentrionale (Muong Peun) des vallées du Fleuve Rouge et des affluents de sa rive gauche, de la vallée du Song Ca (Nord-Annam). Aux plissements du Pliocène moyen qui dénivelèrent la pénéplaine du Tran Ninh (1.000–1.400 m.) correspond un important mouvement de la Chaîne du Fan Si Pan qui atteignit 1.200 à 1.500 m. de dénivellation. Dans cette Chaîne la pression tangentielle fut si forte que sa partie Nord donne l'impression d'avoir été expulsée au dehors et même refoulée vers le Nord-Est. Il s'est produit une sorte de charriage embryonnaire qui s'est traduit le long du Fleuve Rouge par une flexure compliquée de dislocations et de torsions qui affaissa toute la partie du Tonkin située sur la rive gauche de ce fleuve. Dans la zone surélevée du Fan Si Pan, ces mouvements se traduisirent notamment par un rajeunissement du relief d'une importance telle qu'il se forme encore aujourd'hui, au pied occidental de cette chaîne, d'énormes cônes de déjection; l'un d'entre eux atteint 300 m. de hauteur.

Je rattacherai à ces mouvements l'affaissement du sous-sol du delta tonkinois dont 350 m. de sédiments d'eau douce pliocènes, quaternaires et récents recouvrent hypothétiquement le Mio-Pliocène plissé et probablement marin qui doit normalement se raccorder en amont avec les dépôts fluviatiles plissés du même âge de la vallée du Fleuve Rouge. Au cours de mon exposé sur les tectoniques hercyniennes et plus récentes, j'ai insisté à différentes reprises: 1° sur l'existence dans le Centre-Annam, de dépressions marines, d'affleurements de roches acides et de dislocations avec écrasements principalement dans les massifs en bordure de la mer, le tout possédant la même direction Nord-Sud et suivis au Pliocène et au Quaternaire de soulèvements qui s'observent parallèlement au littoral, aussi bien dans les massifs de l'Arrière-Pays que près de la côte et auxquels correspond encore aujourd'hui un affaissement pareillement orienté dans le Bas-Laos et le Cambodge où les alluvions récentes surmontent des alluvions anciennes latéritisées; 2° sur la présence d'épaisses coulées basaltiques dont les centres d'éruption sont principalement situés suivant la même direction Nord-Sud ou encore sur des cassures orthogonales à cette direction. Ce dernier cas est celui des plateaux basaltiques du Cambodge, de la Cochinchine et du Sud-Annam qui sont disposés suivant un arc prolongeant à l'Est l'axe du grand lac du Cambodge. Ces particularités structurales, jointes à ce que l'on connaît de la structure géologique de Bornéo, ainsi que certaines considérations concernant l'allure des isobathes dans les mers de Chine, et aussi la paléontologie récente, m'avaient déjà fait émettre, en 1937, l'hypothèse de la séparation définitive de Bornéo au Quaternaire; cette rupture se serait produite le long d'une fracture Nord-Sud située sur l'emplacement du golfe liasique de Bornéo. C'est sous l'influence de la force centrifuge que ce continent aurait ensuite dérivé vers le Sud. Depuis, les recherches de E. Saurin sur le Centre-Annam permettent d'apporter quelques précisions sur cette question, qu'un examen de la carte géographique semble encore devoir confirmer; on est frappé, en effet, quand on

jette un coup d'oeil sur le dessin de la côte orientale de cette partie de l'Indochine, de constater que sur toute sa longueur elle est déchiquetée en dents de scie allongées vers le S.S.E., tout comme si elle s'était rompue suivant des arrachements par étirements dans cette direction. La côte occidentale de Bornéo présente également un dessin analogue et en sens inverse, mais beaucoup moins accusé; elle montre toutefois un bord affaissé, cependant que celui du Centre-Annam qui lui était opposé est fortement surélevé.

CONCLUSION

On a pu se rendre compte, dans le bref exposé qui précède, que l'Indochine et l'ensemble des guirlandes insulaires du Sud-Est de l'Asie n'étaient qu'un pan détaché de la plateforme eurasiatique et plus ou moins séparé d'elle et de l'Inde péninsulaire depuis une époque très ancienne par les deux plus importantes branches de la Tethys orientale. Dans ce milieu, l'ensemble de l'Asie sud-orientale se serait comporté comme un immense radeau dont les mouvements de dérive auraient été réglés aux différentes époques de son histoire géologique par le jeu des serres. Dans ce jeu, le prolongement Nord-Est de la serre méridionale agissant au Nord de l'Assam—dans une région qui peut être considérée comme le point crucial des tectoniques ayant engendré les arcs de l'Insulinde—aurait produit des poussées plus fortes ayant eu comme résultats, à différentes époques, la fermeture de la Tethys accompagnée de l'émersion de surfaces importantes de la Chine et de l'Indochine, notamment, et la division en arcs du Sud-Est de l'Asie. De telles émersions sont particulièrement nettes à la fin du Silurien, au Moscovien avant le dépôt des couches à *Neofusulinella bocki*, au Permo-Trias, enfin au sommet du Trias supérieur. On a vu, en outre, que ces émersions à l'exception de celle du Permo-Trias, précédaient les ultimes paroxysmes des mouvements ayant produit les divers édifices tectoniques. Ces émersions étaient ensuite suivies d'un relâchement des serres accompagnant de nouvelles disjonctions des arcs. De semblables phénomènes ont été enregistrés au Dévonien inférieur, au Moscovien et au Trias inférieur. Les affinités des faunes et des flores parlent également dans le même sens: depuis l'Ordovicien, les faunes de l'Indochine présentent un grand nombre de formes qui se retrouvent dans les mers eurasiatiques. Quant aux flores, leurs affinités sont d'abord avec l'Eurasie, puis elles contiennent à partir du Permo-Trias, de nombreuses espèces du continent de Gondwana.

APPENDICE.—LES POSSIBILITÉS MINIÈRES

La prospection minière de l'Indochine n'a fait l'objet de recherches méthodiques qu'à partir de 1939. Antérieurement, les recherches faites par des prospecteurs isolés et sans grands moyens, beaucoup plus souvent que par des groupes financiers sérieusement équipés dans ce but, n'avaient pas obtenu d'appréciables résultats; la plupart des gîtes minéraux exploités en Indochine: charbonnages de l'Est du Tonkin, étain et wolfram du Pia-Oac, zinc de Chodien, or de Bong Mieu, étain du Nam P'a Tène, pierres précieuses de Païlin étaient connus depuis longtemps. Le Service Géologique de l'Indochine dont l'orientation était scientifique ne pouvait qu'accessoirement s'occuper de ces questions. En 1934, la prospection géologique minière fut cependant inscrite au programme, mais aucun crédit ne lui fut accordé jusqu'à la veille de la guerre. Les résultats obtenus depuis furent encourageants, mais malheureusement, encore sans lendemain.

Parmi les gîtes d'origine sédimentaire, les formations à apatites de Lao Kay que le hasard avait fait découvrir et dont j'avais montré dès 1934 l'énorme extension donna lieu à des recherches sur une trentaine de km. de distance N.W.–S.E. et aussi à quelques exploitations. Une dernière visite à ces gisements en 1942 me permit de constater que leur minéralisation était liée à des venues stannifères. Ces gîtes dépasseraient en importance ceux de la presqu'île de Kola.

Dans le bassin supérieur de la Rivière Noire et du Song Ma les dernières recherches géologiques m'ont montré l'existence de grandes épaisseurs de grès et de schistes marneux souvent rouges du Norien qui contiennent en de nombreux points du charbon gras à 27 pour cent de matières volatiles et aussi de l'anthracite. La prospection de ce bassin dont l'étendue est considérable n'a pas encore été commencée.

Des gîtes filoniens et de contact découverts directement ou par renseignements ont été visités ou prospectés dans le Tonkin et le Haut-Laos; ils intéressent le cuivre et aussi, pour l'un deux, l'étain et même le cobalt. Dans le Nord-Ouest du Tonkin, il s'agit de deux affleurements de chalcopyrite formant des filonnets ou des masses altérées dans des quartzites et dans des schistes anciens. Dans le Haut-Laos, entre Nam Ou et Nam Beng, E. Saurin a signalé un petit gîte de chalcopyrite altérée en carbonates. Les plus importants affleurements de ces minérais ont été trouvés au contact du granite au S.S.W. du Tran Ninh. Ce sont des minérais complexes contenant principalement de la chalcopyrite et de la blende, avec or, argent, étain et cobalt. J'ai reconnu sporadiquement ces gisements sur une distance de 3 km.; les granites de leurs contacts contiennent de la cassitérite.

À ce type de gîtes métallifères, il y a lieu de rattacher des imprégnations plus ou moins diffuses de molybdénites et de différents sulfures dans les granites de Krong Pha, au pied Sud-Est du plateau de Dalat et le quartz aurifère, particulièrement riche en or, de la Délégation de Pak Lay.

Je mentionnerai enfin, certains produits d'altération sur lesquels j'ai attiré l'attention à différentes reprises: bauxite d'origine basaltique du Tonkin occidental (Dien Bien Phu), dont l'importance n'a pu encore être appréciée, et fer du Nord-Ouest du Tonkin et du Tran Ninh. Ce sont: des fers magnétiques à Ma Lou Tang dans le Nord-Ouest du Tonkin et de l'hématite au Tran Ninh où ce minérai occupe de grandes surfaces situées à 40 km. à l'Ouest des gisements de cuivre et d'étain précités. Ce fer serait en relation avec des sulfures, pyrite et chalcopyrite. Ces quelques résultats récents, auxquels pourraient s'en ajouter sans doute d'autres sur les hydrocarbures si nos recherches avaient pu aboutir, montrent avec éloquence que l'Indochine n'est pas dépourvue de ressources minérales.

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LE BASSIN FERMÉ DU CHOTT ECH CHERGUI

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Algeria

RÉSUMÉ

Les " Hautes Plaines " algériennes sont formées essentiellement par une série de bassins fermés, dont les parties basses sont occupées par des chotts; un chott correspond donc à la zone des points bas d'un bassin hydrographique et hydrologique fermé; c'est une vaste étendue plate faite de terrains salés toujours humides, malgré la permanence d'un climat sec.

Le Chott Ech Chergui se trouve au Sud du département d'Oran; il est situé à la cote 1.000, et sa superficie propre est voisine de 2.000 km²; il occupe le fond d'un bassin fermé dont la surface est d'environ 40.000 km².

Dans le Chott Ech Chergui, où les eaux de ruissellement ne forment que très exceptionnellement une nappe libre, un plan d'eau existe en permanence à quelques décimètres sous le sol; des sources thermales douces, disséminées sur tout le territoire " chotteux," révèlent l'existence d'un système artésien profond et généralisé.

Les études hydrogéologiques ont montré que l'ensemble des sources ne restituait que le 1/20 environ des eaux probablement infiltrées sur l'ensemble de la cuvette, le reste, soit 20 mètres cubes-seconde environ, devant être évaporé par la surface du chott.

Les recherches et travaux en cours ont pour but de soustraire cette eau à l'évaporation, et de mobiliser ainsi chaque année environ 500 millions de mètres cubes d'eau douce.

COMPRISES entre l'Atlas tellien au Nord et l'Atlas saharien au Sud, les Hautes-Plaines algériennes forment dans l'ensemble une vaste gouttière orientée sensiblement Ouest-Sud-Ouest—Est-Nord-Est. Elles ont une superficie de quelque 100.000 km². soit une étendue à peu près égale à celle du Tell (zone peuplée et bien mise en valeur), et au 1/6 de celle de la France métropolitaine.

L'altitude du fond de cette gouttière passe de 1.000 m. aux abords de la frontière marocaine à 400 m. dans la zone du Chott el Hodna, pour remonter ensuite vers la frontière tunisienne.

C'est par excellence le PAYS DE L'ALFA ET DU MOUTON, à très faible densité de population composée essentiellement de bergers indigènes nomades et de quelques Européens dirigeant l'élevage ovin et l'exploitation de l'Alfa.

En réalité, cette forme générale " en gouttière," déprimée au niveau du Hodna et se pinçant vers l'Est, est faite d'une succession de bassins topographiquement fermés dont les limites méridiennes, si elles sont peu marquées, n'en existent pas moins, interdisant tout écoulement superficiel du Maroc vers le Hodna. Et la partie centrale et déprimée de chaque bassin est occupée par un *Chott*, vaste étendue de terrains salés toujours humides, malgré la permanence d'un climat sec.

I. INDIVIDUALITÉ GÉOGRAPHIQUE DU CHOTT ECH CHERGUI

Le CHOTT ECH CHERGUI,—et les chotts voisins (GHARBI et TIGRI), qui peuvent être considérés comme des annexes du premier—, se trouve au Sud du Département d'ORAN (voir Carte au 1/5.000.000e). Il est situé aux environs de la cote 1.000 et sa superficie propre est voisine de 2.000 km².; il occupe le fond d'un bassin fermé dont la surface est de quelque 40.000 km². A la triple particularité de son étendue, de l'immensité de son bassin versant et de son altitude relativement élevée, le CHOTT ECH CHERGUI (s.l.) ajoute une remarquable singularité: il est compris entre deux anciens chotts, zones des points bas de deux bassins hydrographiques et hydrologiques jadis fermés et aujourd'hui " capturés." Les chotts à présent ouverts et en cours de lente et partielle vidange sont:

—le CHOTT de BERGUENT à l'Ouest, en territoire marocain, dont le bord nord-occidental a été ébréché par le haut OUED ZA, affluent de la MOULOUYA;

—le Chott de MASSILINE à l'Est, dans le Sud du Département d'ALGER, et dont la bordure septentrionale a été attaquée par l'important OUED CHELIFF. La capture s'est faite au lieu dit BOUGHZOUL; elle a presque doublé la superficie du bassin versant de la rivière, puisque l'ancien bassin fermé couvrait 20.500 km². pour 24.500 km². correspondant au bassin du Chéliff à l'aval de BOUGHZOUL.

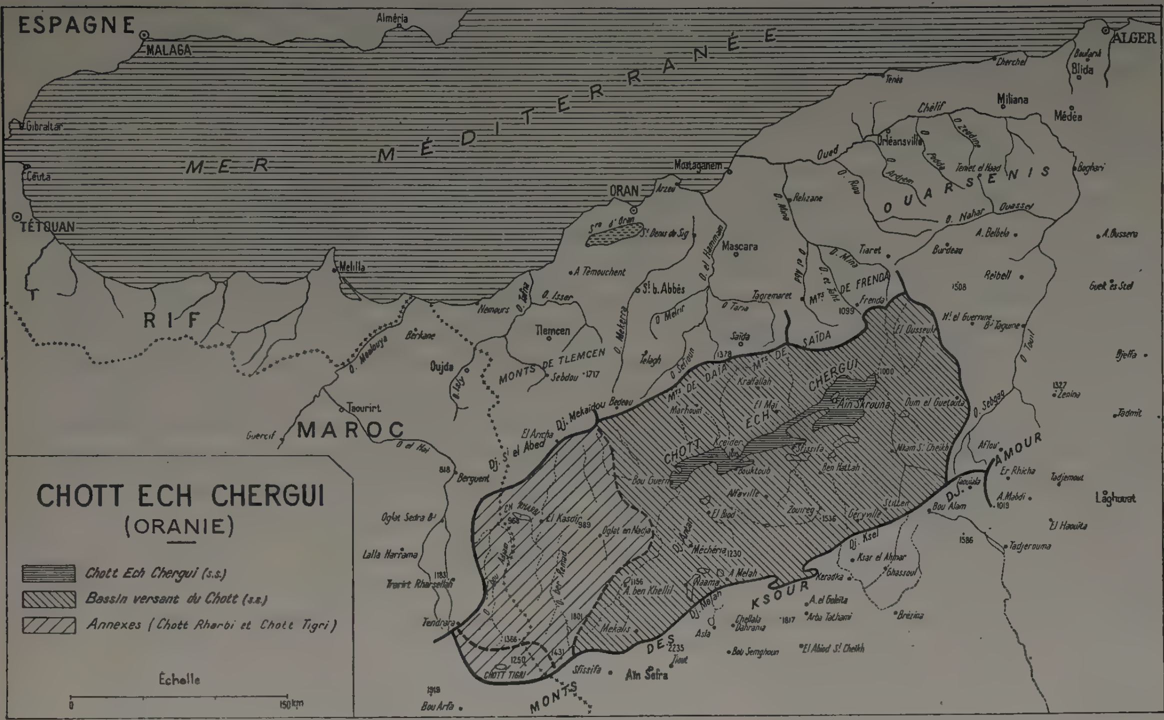

FIG. 1.

Quoi qu'il en soit, on retiendra, du point de vue géographique, que le Bassin du CHOTT ECH CHERGUI (s.l.) est bien individualisé et qu'il offre de très remarquables particularités.

II. STRUCTURE GÉOLOGIQUE GÉNÉRALE

Les terrains qui affleurent au Nord sont constitués essentiellement par des formations calcaires et dolomitiques appartenant à la partie supérieure du JURASSIQUE SUPÉRIEUR (KIMERIDGIEN-PORTLANDIEN) reposant sur un ensemble essentiellement marneux correspondant au CALLOVO-OXFORDIEN et au LUSITANIEN.

Ce n'est que dans la partie Nord-Est du bassin que l'on voit apparaître des dépôts du CRÉTACÉ INFÉRIEUR, généralement argilo-gréseux, rapidement surmonté par une formation gréseuse attribuable à l'ALBIEN et représentant sans doute à ce qu'on appelle ailleurs (Atlas saharien et Sahara) le CONTINENTAL INTERCALAIRE, énorme complexe généralement perméable qui a une très grande importance au point de vue hydrologique.

Au Sud, la série commence avec du TRIAS gypso-salin dont les affleurements, très remarquables, sont cependant fort réduits en étendue. Puis vient la succession normale: LIAS CALCAIRE puissant et couvrant de grandes superficies, DOGGER (p.p.) argilo-gréseux ou marno-calcaire peu épais, JURASSIQUE SUPÉRIEUR (s.l.) et CRÉTACÉ INFÉRIEUR très généralement gréseux, APTIEN marin sous forme de marno-calcaires minces (parfois absents = lacunes), CONTINENTAL INTERCALAIRE puissant et probablement "*albien*," CÉNOMANIEN (p.p.) marno-gypseux et enfin TURONIEN calcaire puissant surmonté d'un SÉNONIEN marneux très réduit ici.

Ces deux régions font l'objet actuellement d'études détaillées, mais nous en savons assez, pour l'heure, quant au problème général qui nous occupe.

Toute la zone moyenne de la gouttière est remplie par des atterrissements argilo-sableux ou argilo-calcaires très puissants, d'âge probablement MIO-PLIOCÈNE, sur lesquels nous reviendrons plus loin. Et c'est dans la partie la plus déprimée de la cuvette que s'étire d'Ouest en Est l'immense CHOTT ECH CHERGUI, long de 160 km. et dont la largeur varie entre 8 et 40 km. Le sous-sol est fait des atterrissements

précédents et seul le sol, sur quelques mètres d'épaisseur, est constitué par un curieux magma de vase grisâtre bourrée de cristaux de sels divers où le gypse prédomine.

Au point de vue structural, on a affaire à un grand synclinorium dont la partie médiane a été remblayée par les atterrissements précédents, la partie " chotteuse " actuelle paraissant en voie de déflation éolienne.

De ces atterrissements sort lentement au Nord un énorme anticlinal peu accusé, mais dont la structure de détail est compliquée de synclinaux secondaires à peine marqués et de cassures assez importantes (Djebel Toual). Au Sud au contraire émergent de ce remblaiement des anticlinaux aigus à axe exceptionnellement triasique (Djebel Melah de Méchéria), souvent liasique (Djebel Antar de Méchéria), très fréquemment jurassique supérieur (Djebel Ksell de Géryville). Les synclinaux intercalaires sont larges et plats lorsqu'ils sont faits de grès (Crétacé Inférieur ou Albien), en " fond de bateau " quand ils sont constitués par des calcaires (Turonien).

Les axes anticlinaux peuvent être suivis sur d'assez grandes distances, puis s'ennoient brusquement et fortement, soit pour reparaître, ce qui est l'exception, soit pour passer à un large synclinal très calme, pendant que d'un synclinal voisin, fort tranquille jusque là, naît brusquement un anticlinal aigu; c'est le style classique des plis " en chenilles processionnaires " de l'Atlas saharien. Et dans toute cette zone méridionale, fortement plissée, les accidents sont fort rares.

Du tréfonds des atterrissements, on ne sait pratiquement rien, ce qui est grave, puisque le bord Nord est très différent du bord Sud; et l'on pense que l'on n'aurait jamais pu lever cette inconnue, si le problème hydraulique n'avait exigé que l'on tente une reconnaissance précise par tous les moyens possibles; cette reconnaissance est en cours, et si l'heure des conclusions approche, le moment n'est pas venu de donner des résultats encore trop fragmentaires.

Quoi qu'il en soit, tel est le cadre général dans lequel s'inscrit le Chott Ech Chergui: une large auréole d'atterrissements monotones couverts d'alfa, formant aussi, par un très léger relèvement topographique, les bords Est et Ouest du tableau; au Nord, une bordure très douce formée essentiellement par un anticlinal calcaire; au Sud, une large bande constituée par une série de plis aigus, la ligne de partage des eaux passant, à une exception près (synclinal du Djebel Guerdjouma), par la ligne de crête d'une série d'anticlinaux bien marqués; dans cette bande, les arêtes sont tantôt gréseuses, tantôt calcaires, les dépressions larges étant le plus souvent gréseuses.

III. HYDROGÉOLOGIE

Ce Pays steppique, à cause de son altitude moyenne élevée et des reliefs accusés qui le bordent au Sud, n'est pas des plus mal arrosés; certes, au niveau du chott, les précipitations descendent à 200 mm. par an; mais au Nord, elles dépassent 300 mm. et elles montent au Sud (région de Géryville) à plus de 400 mm. L'ensemble, du point de vue climatique, peut être caractérisé par les traits suivants: hauteurs de pluies faibles en moyenne, pluviosité très variable, vents forts, écarts journaliers de température importants, sécheresse tout à fait remarquable de l'atmosphère. Le bassin du Chott Ech Chergui est donc un immense pays sec, peu arrosé, et arrosé d'une manière capricieuse, battu par les vents, franchement continental, et baigné sans cesse par un air avide d'eau.

Mais que deviennent, dans ces conditions, les quelque 12 milliards de m^3. d'eau qui, chaque année et bon an mal an, tombent sur l'impluvium considéré? Sous ce climat, une part très importante doit évidemment être reprise par une évaporation quasi instantanée.

Cependant, il est indubitable qu'une partie de cette masse d'eau est ruisselée, et une autre infiltrée. Pour la première, on peut observer qu'il existe un réseau hydrographique important pour lequel le Chott constitue le " niveau de base." Tous ces petits oueds ont des thalwegs plus ou moins bien marqués, mais très généralement à sec.

Au moment des précipitations importantes, ils coulent évidemment, mais contrairement à ce que l'on pourrait croire, la plus grande partie des eaux n'arrive pas au chott, soit que ces eaux s'infiltrent dans les grès et calcaires des affleurements du bed-rock, soit qu'elles soient absorbées par les atterrissements. Pour ces derniers, on doit distinguer ceux qui, argilo-sableux et reposant généralement sur des

grès, gardent une bonne perméabilité généralisée, de ceux qui, argilo-calcaires en général, et supportés par des calcaires, montrent d'innombrables cheminées d'absorption, sortes de " bétoires " comblées, mais certainement absorbantes. Dans ce cas particulier, les parties supérieures des cheminées correspondent à des " daya," dépressions fermées en général, ou zones d'épandage des oueds dans lesquelles les eaux finissent par disparaître, en partie évaporées, en partie infiltrées.

Quoi qu'il en soit, force est de constater que le chott, réceptacle naturel des eaux ruisselées, ne montre généralement pas de nappe liquide; et les cônes de déjection, au débouché des vallées, sont fort peu importants. En fait, depuis trois ans, les rivières n'ont coulé jusqu'au chott qu'au cours de l'hiver dernier, grâce à des précipitations particulièrement importantes. Dans ce cas, le chott joue évidemment son rôle sans mystère de " surface évaporatoire des eaux sauvages " arrivées jusqu'à lui.

Pour ce qui est des eaux infiltrées, tant dans les terrains perméables des montagnes bordières que dans les formations de remblaiement, une première particularité frappe dès l'abord: s'il existe des sources un peu partout dans les reliefs, il s'agit généralement, quelle que soit la nature du terrain perméable qui les alimente, de pauvres points d'eau à faible débit moyen, montrant parfois des " crues " brutales et brèves étroitement liées aux précipitations, tarissant ensuite rapidement, mais gardant toujours un plan d'eau visible à faible profondeur sous le sol. Ce sont là, en somme, des " puits-sources " fonctionnant comme des piézomètres naturels décelant l'existence de ressources aquifères dont les variations des charges piézométriques ont des amplitudes généralement faibles.

Corrélativement, il faut observer que, contrairement à ce que l'on pourrait penser a priori, c'est dans le chott lui-même, zone pourtant très faiblement arrosée, que l'on trouve les sources les plus remarquables tout à la fois par l'importance et la régularité de leurs débits.

Ces sources sont en fait des griffons artésiens, et leurs eaux montrent toutes une certaines thermalité (22 à 32°) et une minéralisation faible mais réelle (en moyenne, 1,5 g. de résidu sec). Pour une source donnée, la température et la minéralisation (comme le débit) sont pratiquement constantes. Et le CHOTT ECH CHERGUI est parsemé d'un grand nombre de ces sources artésiennes naturelles marquées, sur la surface plane du bas-fond, par un cône très plat correspondant au dépôt des sels laissés sur place par l'eau évaporée sur une très faible surface.

La plus importante de ces sources est l'AÏN SKROUNA, qui débite 500 litres à la seconde, créant un marécage d'une vingtaine de km². et déposant ainsi chaque jour quelque 70 tonnes de sels; à ce régime, une île s'est formée, dont le point culminant est à 6 m. environ au-dessus du chott, et dont la superficie dépasse 25 km². L'AIN SAOUSS, plus modeste, ne débite qu'une centaine de litres à la seconde, mais fournit un exemple parfait de griffon artésien sortant à la lisière d'un cône de dépôt, et épandant ses eaux sur une " presqu'île " en cours de surélévation. Quand une certaine cote sera atteinte, le griffon se déplacera, jusqu'au moment où les eaux, trop considérablement freinées dans cette zone, s'en iront sortir ailleurs.

Le cas d'un griffon pratiquement tari est réalisé en bien des points du chott, où sont groupés des îlots dont un seul est resté faiblement productif, et ne peut manquer de voir sa source tarir avec le temps.

Nous avons toujours pensé qu'il y avait une relation entre le régime spécial des points d'eau naturels (puits-sources) de l'impluvium, et l'existence des remarquables sources artésiennes du chott. Mais l'étude de cette relation nous paraissait naguère encore fort difficile et vraisemblablement sans intérêt.

Cependant, à l'occasion de recherches entreprises pour la solution d'un problème d'alimentation en eau d'une importante industrie, nous fûmes amené à aborder cette étude.

Un bilan hydraulique théorique, établi selon les méthodes habituelles employées en hydrogéologie, fit apparaître que le poste " infiltrations " devait être, pour l'ensemble de l'impluvium du chott, de l'ordre de 600 millions de m³./an; encore n'avions-nous pris, comme bases de nos supputations, que des chiffres approchés par défaut!

Le poste " restitution," convenablement établi, ne révéla, pour l'ensemble du même impluvium, sources du chott comprises, qu'un rendement de l'ordre de 30 millions de m³./an.

Après de multiples vérifications et une longue période de réflexion, on dut admettre que nos chiffres, pris seulement comme ordres de grandeurs, ne pouvaient être faux, et qu'un important phénomène particulier venait ici rendre illusoire l'établissement d'un bilan hydraulique basé sur des méthodes correspondant à des cas simples et connus; nous étions évidemment en présence d'un cas particulier non encore étudié, au moins à notre connaissance.

De nos observations, dont la principale trouve son origine dans le fait que, sous climat sec, la surface du chott est cependant toujours humide, naquit l'hypothèse suivante:

La plus grande part des eaux infiltrées sur l'impluvium du Chott Ech Chergui, à une altitude supérieure à celle du chott proprement dit, vient former, dans la zone de ce chott, une énorme ressource aquifère profonde qui trouve, pour une faible part de ses possibilités régularisées, des exutoires visibles aux environs de la cote 1000, c'est-à-dire un peu au-dessus de l'altitude du chott. Le renouvellement annuel de cette ressource est au minimum de l'ordre de 600 millions de m^3. (infiltration moyenne: 5 pour cent). L'équilibre hydraulique, naturel et indispensable, est réalisé, pour une petite partie par le débit des sources précitées, et pour une très grande partie par évaporation au niveau et par toute la surface du chott. Celui-ci n'est dès lors qu'une énorme machine évaporatoire naturelle qui réalise l'équilibre du système en dilapidant, en plus des eaux apportées par ruissellement, la plus grande part de son revenu hydraulique souterrain.

Sur cette base, il fut évidemment aisé de calculer que, pour les 2.000 km^2. de surface évaporatoire, la tranche évaporée devait être de l'ordre de 30 cm./an, chiffre tout à fait admissible ici, compte tenu de tous les facteurs tant favorables que défavorables.

Mais on en déduisit aussi que, dans l'Algérie où l'eau est à la base de toute vie et constitue le fondement d'une mise en valeur souhaitée par tous, ce gaspillage naturel était inadmissible. Ainsi fut décidée la création du " Centre d'études Hydrauliques du Chott ech Chergui," installé à proximité même de l'imposante Ain Skrouna et chargé de vérifier, par tous les moyens possibles, l'hypothèse émise ci-dessus, et de trouver les moyens de mobiliser l'eau dilapidée en la soustrayant à l'évaporation. Si la ressource à récupérer est de l'ordre de 600 millions de mètres cubes par an, l'effort à tenter est justifié; car dominant l'Oranie aride où existent pourtant de riches terres basses, c'est la perspective de la mise en valeur de quelque 200.000 hectares actuellement pauvres qui s'ouvre ainsi; et pour passer de la cote 1000 à l'altitude 200, c'est aussi la possibilité de produire plus d'un milliard de kilowatt-heures par an qui est ainsi ouverte. Ces deux éléments sont susceptibles de modifier profondément les conditions économiques de l'Algérie occidentale.

IV. ÉTUDES EN COURS ET PRINCIPAUX RÉSULTATS ACQUIS

Au Centre d'études de l'Aïn Skrouna, où travaillent des géologues, des météorologistes, des physiciens, des chimistes, des géophysiciens, des sondeurs et des puisatiers, de nombreuses recherches ont été entreprises depuis deux ans, des procédés de mesures ont été mis au point, des méthodes d'investigation ont été crées; nous n'entrerons pas dans le détail, mais nous retiendrons seulement quelques-uns des principaux résultats acquis, et dont le mérite revient à tous les chercheurs qui participent aux études.

(1) Dès qu'un forage atteint, sous les atterrissements du chott, un terrain perméable, on obtient un jaillissement artésien d'eau douce.

(2) A la bordure Nord, ce terrain est constitué par des calcaires du Jurassique supérieur fortement diaclasés; et l'Aïn Skrouna, comme sans doute les sources artésiennes les plus importantes, se trouve sur une ride formée par ces calcaires, ride qui les amène à quelques dizaines de mètres sous le sol; vers le Sud, existent une ou plusieurs fosses très profondes, comblées par des atterrissements dont l'épaisseur peut avoir plusieurs centaines de mètres.

(3) Jusqu'ici, l'artésianisme est donc général sous tout le bassin. En fait, le niveau piézométrique est à environ 7 m. au-dessus du chott; il ne s'agit pas là du niveau hydrostatique théorique, puisque nous sommes ici dans la zone perturbée par l'écoulement des sources; et en réalité, il ne peut y avoir un niveau hydrostatique réel, puisque toute la masse d'eau est en mouvement, ainsi qu'on va le voir.

(4) L'humidité permanente de la surface du chott est facilement explicable; il existe en effet immédiatement au-dessous de cette surface, un plan d'eau généralisé qui s'établit, d'après les observations faites et selon le moment de l'année, entre 0 et 70 cm. de profondeur; la tranche située au-dessus du plan d'eau est la zone des échanges entre la nappe et l'atmosphère. Une sorte d'équilibre s'établit ainsi: dès que l'évaporation augmente, le niveau baisse, et réciproquement. Ce niveau est donc régi tout à la fois par les conditions atmosphériques et par les vitesses de circulation dans les dépôts d'atterrissement, la charge restant, à très peu près, constante. Si la perméabilité était plus grande, il s'établirait sans doute, à certains moments, un véritable lac, mais par la suite, l'assèchement serait plus rapide, et le plan d'eau, à d'autres moments, se trouverait plus bas que les minima observés. En l'état actuel, la " machine " est bien équilibrée et fonctionne pratiquement sans à-coups.

(5) Le mouvement ascendant des eaux a été vérifié par de nombreux piézomètres, forés dans les alluvions; le milieu n'est évidemment pas " homogène et isotrope," et le moment n'est pas venu de donner une valeur, même moyenne, des vitesses de circulation.

(6) Mais nous avons parlé de " perméabilité " pour des terrains d'atterrissement argileux, évidemment très fins et très fragiles dans la tranche superficielle. Des mesures courantes, faites sans précautions spéciales, avaient effectivement donné, pour la perméabilité, des chiffres très faibles. Il est vrai que les argiles du chott, lorsqu'elles sont prélevées sans soins particuliers, sont peu perméables, ce qui est normal pour des argiles. Mais *en place*, ces argiles montrent un nombre incalculable de canalicules, dont le diamètre va de 0,5 à 5 mm., dirigés préférentiellement de bas en haut, avec cependant des anastomoses latérales. En fait, depuis l'origine du remblaiement, les eaux du bed-rock ont toujours lutté contre l'occlusion; la charge fournie par les affleurements alimentaires leur a toujours permis de triompher de la sédimentation argileuse, quelle que soit, dans toute l'étendue du chott, l'épaisseur finale du faux " couvercle." Les canalicules permettant l'ascension des eaux à travers la masse des atterrissements sont la règle; mais par places, le bed-rock pouvait avoir primitivement d'importants exutoires libres: à leur verticale s'est constituée, depuis l'origine du remblaiement, une cheminée permettant la sortie des eaux; ainsi étaient pré-indiquées les grosses sources du chott; une telle cheminée, quant à son origine, n'est rien autre qu'un énorme " canalicule."

Nous ne dirons rien de l'évolution de ces sources et du chott lui-même, en fonction d'un éventuel remblaiement supplémentaire ou d'un déblaiement progressif; les phénomènes sont à présent aisés à imaginer, et ils ne seraient sans doute pas visibles à l'échelle humaine; ils le seront d'autant moins que, au point où en sont rendues les études, on peut penser que l'homme va perturber tout cela.

Mais nous nous devons d'ajouter que nous n'avons pas la prétention d'avoir tout résolu. Techniciens et Scientifiques oeuvreront encore longtemps pour apporter, chacun dans sa spécialité, une preuve de plus de la réalité et de l'intérêt du phénomène. En particulier, du seul point de vue des mesures théoriques, l'évaluation, directe ou indirecte de l'évaporation moyenne occupe bien des chercheurs; il en est de même de l'étude des effets capillaires dans les canalicules; il en est encore de même de la mesure des vitesses de remontée, et du problème important de la structure profonde du chott et des relais entre les calcaires liasiques et les grès jurassiques et crétacés du Sud, et les calcaires du Jurassique supérieur du Nord. Et du côté pratique, la question de la mobilisation de l'eau et de son exhaure, et aussi celle des effets de la vidange, sans parler des études touchant à l'utilisation des eaux obtenues, seront peut-être longues à résoudre et à mener à bien.

Mais on croit bien qu'une certitude est d'ores et déjà acquise, car rien n'est venu infirmer l'hypothèse de base; et pendant que se termineront les études du CHOTT ECH CHERGUI, d'autres recherches commenceront sur d'autres chotts, tant " steppiques " que " sahariens "; car nous savons déjà que tous les chotts se ressemblent et relèvent du phénomène brièvement décrit ci-dessus; et aussi que l'individualité topographique des bassins, déjà fort peu marquée, n'existe probablement plus en profondeur, et qu'il est possible, sinon probable, que les ressources souterraines qu'ils renferment trouvent dans certaines zones des liaisons plus ou moins faciles. Quoi qu'il en soit, au point où nous en sommes rendu, nous savons déjà que le problème hydraulique du CHOTT ECH CHERGUI est susceptible de généralisation au moins dans toute l'Afrique du Nord, et vraisemblablement bien au delà.

GEOLOGICAL HISTORY OF THE IRON ORES OF CENTRAL SWEDEN

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ABSTRACT

Discussion of origin and metamorphism of the Archaean ore types. The associated rocks are metamorphic siliceous volcanics (leptites and hälleflintas) and interstratified limestone; no older formation is known in the region. The quartz-banded ores (hematite or magnetite) are interpreted as chemical sediments, their iron and silica having reached the surface through some kind of volcanic after-action. The " skarn and limestone ores " (magnetite) form a seemingly rather homogeneous group, but represent a remarkable diversity of origin. A very large part originated as sediments or as " shallow " replacements in carbonate rocks. Their skarn minerals are due to later metamorphism caused by the first group of Archaean granites, and developed only where free silica and carbonates occurred together in the ore deposit (" reaction skarn ores "). Additions from the granites resulted also in chemical alterations. Certain skarn and limestone ores, again, were formed entirely through contact metasomatism caused by these granites (" primary skarn ores "). The third group, the apatitic ores (mainly magnetite), is regarded as due to magmatic processes connected with the volcanism and similar to those that gave rise to the Kiruna deposits in Northern Sweden.

IN the geological study of iron ores in Sweden and particularly in the genetic interpretation of these deposits, the two iron-bearing regions of the country have presented widely different aspects. The huge ore bodies of the northern region, as at Kiruna and Gellivare, exhibit a remarkable simplicity in their geological relations, and the rocks and ores are, in part of this region, comparatively little affected by metamorphism. Therefore all students agree in the general genetic interpretation of the ore bodies, regarding them as differentiation products of the same magmatic derivation as the associated porphyries. Admittedly, the details of the differentiation and the physico-chemical processes involved are, however, still largely obscure.

The region of Central Sweden, with its enormous number of iron-ore deposits—mostly of moderate or small size—occurring in generally rather strongly deformed, metamorphic rocks, and themselves partly affected by secondary changes, have offered a more difficult problem, as is witnessed by the rather wide divergence of opinion on important points that existed until recently even among those who had seriously tried to penetrate the problem. In order to clear up, as far as possible, the problems under discussion and to present a general survey of this ore-bearing region, for the benefit of geologists and miners alike, the authors about 1930 started joint work, adding new monographic studies to those already accomplished and filling out with more rapid surveys the spaces between these fields of detailed studies. The work was done in the Geological Survey of Sweden, with contributions from the Jernkontoret (Iron producers' Association of Sweden). The report was published in Swedish, in order to simplify its study for practical purposes. The summary now to be given presents only those results that are of a purely scientific and general interest.

The iron ores of Central Sweden form units of the Archaean of this region, therefore their interpretation necessitates a most thorough study not only of the deposits themselves, but also of the whole Archaean complex in which they are contained.

The Archaean rocks of the region can be divided into four main groups (leaving aside a number of basic intrusions of moderate volume and without immediate bearing on the problem of genesis). The three oldest groups, designated as the Svionian cycle, are, in order of age: (1) the supracrustal leptite series, which contains the ore deposits; (2) the older granite group (" *urgraniter* "), and (3) the younger granite group. The fourth group comprises granite bodies of a later Archaean cycle, the

Gothian. The relations between the Svionian groups are essentially these: the leptite series is closely folded and generally occurs as bands of varying width, separated from each other by bodies of the oldest granite group which have been intruded concordantly with the structure of the folded leptite series, probably mainly during later stages of this folding epoch; the later Svionian granites, again, appear as cross-cutting intrusions apparently more or less independent of the earlier structures and have in certain parts, particularly in some border zones of the region, been connected with a wide and intensive metamorphism of the older rocks, in the form of a strong migmatitization.

Leaving out for the moment the ore deposits, the leptite series may be described as a sequence of hälleflintas and leptites with intercalated beds of limestone and dolomite, and, in certain districts, an upper group of originally clastic sediments such as quartzites and phyllitic slates. Since the terms " hälleflinta " and " leptite " have been introduced by Swedish geologists, and our colleagues from other countries have found it difficult to understand the need for these special names, it may be advisable to define them here. " Hälleflinta," in literal translation " rock flint," is a rock with a typical conchoidal fracture, and without any visible granularity in the main mass although well-defined phenocrysts often occur. Microscopical examination shows that the hälleflintas invariably have the character of a volcanic rock, of rhyolitic or dacitic composition and either a lava or a tuff. The lavas are massive, the groundmass being finely even-grained or showing well-preserved primary textures such as poikilitic or granophyric intergrowths, spherulites, etc. The tuffs, often well bedded, sometimes exhibit the very characteristic microtextures of a volcanic ash deposit. Essentially, therefore, the hälleflintas are siliceous volcanic rocks, devitrified but otherwise very little changed. However, hälleflintas appear only in some limited districts, as at Grythyttan, where Dr. Sundius made a most valuable study of them 25 years ago, or at Dannemora. In the rest of the region, the volcanics have undergone a decided metamorphism which has turned them into leptites. This means that the groundmass has secondarily increased in grain size. As practical figures, we use 0·03–0·05 mm. for a lower limit, against the hälleflintas—this being the size when the typical conchoidal fracture disappears and it becomes clear that the rock has a granular texture, although the individual grains cannot be discerned by the unaided eye. The upper limit has, more arbitrarily, been set at 0·5 mm.; above this figure, the term leptite gneiss is preferable. Phenocrysts of feldspar and quartz are often well preserved, but particularly the former may break down into granular aggregates. Judged by outcrop area, the leptites, as here defined, by far predominate in this series.

A most remarkable feature of this volcanic sequence is its chemical character. Both in hälleflinta and in leptite facies there appear extremely sodic rocks, and also others with predominant potash feldspar, while intermediate phases are rare. While these features may locally have been brought about by secondary processes, as a rule they must be of primary origin.

Although the series is utterly deformed by folding, certain broad stratigraphical features have been established. Thus it has been shown that there is, at least within large parts of the region, a lower sequence of sodic rocks and an upper one of more potassic varieties.

Dacitic types belong to high levels, and so do the infrequent beds of spilitic greenstones. Limestone or dolomite beds occur at various levels and can often be traced continuously for long distances. The clastic sediments form the uppermost unit.

The older granite group, intruded in connection with the folding of the leptite series, has caused only a moderate textural metamorphism in the older rocks. Closely related to this epoch of intrusions, however, is the widespread and intensive metasomatic alteration that from its most characteristic feature had been called " magnesia metasomatism." This process has caused alterations of regional extent in the leptites, but only in rare cases left traces in the granites themselves. Generally, the alteration cannot be ascribed to any particular granite body (as is the case at Orijärvi in Finland, so ably described by Eskola). But there is no doubt that it was closely related to the epoch of the first granitic invasion, and it seems a safe inference that there was a relation also in cause. The main results are a complete disappearance of the feldspars of the leptites, and an addition of certain substances, especially magnesia. Thus there are districts where areas square miles in extent carry 3·5 per cent MgO as

compared with 0·5 per cent in the unaltered leptites. The altered rocks contain quartz, micas, cordierite, andalusite, almandine garnet, and magnesia-iron amphiboles such as anthophyllite. The majority of the sulphide-ore deposits of the region occur among these altered rocks, either directly in them or in interstratified limestone or dolomite, and are plainly the products of replacement at comparatively high temperatures.

The iron ores—all in the leptite series—may be divided into three main groups: quartz-banded ores, skarn and limestone ores, and apatitic ores. There are some deposits that do not fall within the normal variation limits of these types, but they are rather few and small.

In the quartz-banded ores, the ore mineral is hematite or magnetite, or a mixture of both. As indicated by the name, the ore minerals form thin layers, alternating with layers of quartz. These deposits thus belong to a world-wide Pre-Cambrian type of iron ores—the "banded ironstones." In the Swedish deposits, iron is comparatively high, ranging from about 52 per cent down to 35 per cent, only the varieties of about 47 per cent or more being used without concentration. Phosphorus is low, 0·007 to 0·030 per cent in most cases. Manganese is also low, only a few tenths of one per cent, but there are a few small and siliceous deposits where manganese equals iron, the former then mainly occurring in silicates while there is little or no quartz.

Besides the oxidic iron minerals, and quartz, there sometimes occur, in subordinate amounts, certain silicates, among which andradite garnet is most common. Andradite then forms separate layers—often borders between ore and quartz—and irregular concretionary lumps.

The skarn and limestone ores form a much more inhomogeneous group. The ore mineral is magnetite. The term "skarn," originating from the Persberg mines and taken up as a geological term by Törnebohm, means "waste" and signifies the valueless mineral aggregates that are closely associated with the ore minerals. In practice, this means that the skarn minerals belong to certain groups of silicates mainly of Ca, Mg, Fe, and occasionally Mn. Andradite garnet, pyroxenes belonging to the series diopside-hedenbergite, and amphiboles such as tremolite, actinolite, hornblende, and in certain types anthophyllite, humite minerals, forsterite and serpentine are the ordinary skarn minerals, while manganiferous ores may be associated with minerals such as spessartite garnet, dannemorite amphibole, knebelite or manganiferous fayalite, or rhodonite.

The proportion between magnetite and skarn varies greatly, and so does their mutual distribution in the deposit. Thus big skarn bodies occur, in which workable magnetite concentrations form only subordinate and generally irregular parts. On the other hand, there may be about equal proportions of magnetite and skarn, sometimes alternating in an irregular striping or stratification.

Some skarn ore deposits are directly intercalated in leptites, and then generally have a fairly distinct layered appearance. Others, among them all the more irregular deposits, occur in layers of limestone and dolomite, sometimes as fairly regular layers but more often as more or less irregular bodies.

In what are called "limestone ores" there is little or no skarn; the magnetite occurs in limestone or dolomite, the ore bodies being generally more or less diluted with these carbonates. As among the typical skarn ores, there are varieties that exhibit a fairly good stratification and others that are highly irregular.

No figure can be given for the iron percentage (as contained in magnetite) of skarn or limestone ores, as the workable limit depends also on many other factors, such as textural features favouring magnetic concentration. Phosphorous is very low, even down to figures of 0·003 or 0·002 per cent in whole ore bodies, but sulphur occasionally may be a little high.

For practical and, to some extent, also for theoretical purposes, a distinction is made between manganiferous and non-manganiferous skarn and limestone ores. The lower limit of the former group is put at 1 per cent Mn and the average value may be estimated at about 4 or 5 per cent, figures above 10 per cent being (in unweathered ore) exceptional. The non-manganiferous ores rarely contain more than a few tenths of one per cent of manganese. The manganiferous types are mostly developed as limestone ores, with part of the manganese contained in the associated carbonates, or as basic skarn ores with such skarn minerals as knebelite, the manganese-iron olivine, accompanying the magnetite.

The apatitic ores form high grade ore bodies, generally of magnetite but sometimes of hematite. Often there is some admixture of silicates, as actinolite, which may gather into skarn patches. The phosphorus percentage mostly lies in the neighbourhood of one per cent, corresponding to about 5 per cent of apatite. The phosphate is, in most cases, easily visible, and sometimes gathers into conspicuous segregations, as bands roughly parallel to the boundaries of the ore body. In their relations to their wall rocks, the apatitic ores exhibit a rough concordance with the strike and dip of the leptites, but often send out systems of fissure-filling ore veins into them, or are accompanied by an aureole of partial replacement where the development of skarn silicates is a conspicuous feature. The apatitic ores are more restricted in their occurrence than the other iron ore types.

Already at an early stage in the study of the iron ores of Central Sweden, at a time when the sedimentary origin of all the ore types was accepted as a matter of course, several observers noted the characteristic grouping of deposits of different ore types and concluded that this indicated a certain stratigraphical distribution of these types. Later, in 1906, H. Johansson emphasized another aspect of the association between leptites and ore types, maintaining that the relationship could be expressed in certain chemically characteristic combinations, and basing upon a rather elaborate system of such relations a hypothesis that interprets the whole of the leptite series—leptites, limestones, ore deposits, etc.—as products of differentiation *in situ* in a deep-seated magma. It has turned out, however, that only a few sections of Johansson's complicated system of " chemical relations " remained after more detailed studies had been undertaken, but these details are of considerable importance. As to the origin of the leptite series, its supracrustal character must be regarded as conclusively established.

Among the chemical relations just alluded to, what is called " the manganese criterion " is of special importance. This refers to the fact that, among skarn and limestone ores, the manganiferous varieties are almost invariably associated with potassic leptites, while the ores low in manganese show a decided but not quite so overwhelming statistical preponderance of soda leptite associations.

To turn now to our own interpretation of the various ore types: with regard to the quartz-banded ores, we agree with most previous workers in ascribing the origin of this type to a process of chemical sedimentation. As to the nature of the characteristic banding, we think one must not regard it so much as an alternation of layers of different character (ore and silica) as a series of double layers composed of two components that were precipitated at the same time but settled at different rates. Our views, therefore, are the same as previously expressed by Moore and Maynard. There can hardly be any doubt that the silica was originally precipitated in a colloidal form. There are, in the least metamorphic deposits, striking similarities to the development of the strongly red-pigmented quartz bands of the Lake Superior jaspilites. The character of the original iron mineral is not established with certainty. Siderite seems improbable, because its oxidation to hematite could hardly have left the fine stratification so undisturbed as is now the case. Greenalite is more definitely ruled out, as the ore bands are invariably too pure to have been derived from an original silicate. It therefore seems most probable that a trivalent oxide or hydroxide formed the original iron compound; however, siderite is not entirely excluded.

The source of the iron and silica must be sought in magmatic emanations, such as fumarole gases or thermal springs. All the rocks known to be older than the ores or directly associated with them are very low in iron, and sediments that resulted from weathering are unknown within the leptite series except its uppermost, ore-free parts. Therefore, the possibility that the quartz-banded ores are products of ordinary processes of weathering and sedimentation, as a number of workers have claimed in the case of similar deposits elsewhere, appears to be excluded in the case of the Swedish occurrences.

The skarn and limestone ores present a much more complicated problem—or rather, set of problems. The association with limestone or dolomite, the shape of the ore bodies—at least when not well stratified—and the mineralogical composition are features that seem to indicate an origin by contact replacement (pyrometasomatism) for at least the vast majority of these deposits. Yet this group, however homogeneous it may appear even from a geological point of view, has proved to be quite

inhomogeneous in origin. It is convenient to follow three different lines of advance in its interpretation, each starting from a special sub-type, and see where they lead.

When speaking of the quartz-banded ores, we mentioned the local development of andradite skarn as layers or concretions. It is evident that this garnet forms a reaction product between the hematite layers, quartz layers, and interstratified layers of limestone. Similarly, in more or less clearly stratified skarn ores, one can trace an origin from a similar bedded deposit which originally differed from the variety of quartz-banded ore just alluded to only by its greater quantity of limestone or dolomite layers. This greater proportion of carbonates has increased the quantity of reaction skarn resulting from the metamorphism. In this type, apparently, a sedimentary origin is indicated.

In the manganiferous limestone ores or basic skarn ores, again, a parallel metamorphic history may be traced. These ores, even in their present metamorphic stage, still contain manganiferous and ferrous carbonates mixed with the predominant magnetite, and there are strong reasons for believing that they were originally carbonatic throughout, with only a moderate quantity of quartz gangue. The rather common occurrence of graphite in these ores is, for good reasons, held to have resulted from the thermal dissociation of iron-manganese carbonates. The skarn silicates mixed with the ore are interpreted as reaction products between carbonate ore, quartz, and dolomite. Characteristic is the development of a zone of manganiferous skarn between an ore body mixed with dolomite and its siliceous wall rock (hälleflinta or leptite). Thus again we meet the typical " reaction skarns." As to the original ore-depositing process it is not possible to state with certainty to what extent sedimentation together with the associated dolomite, or " shallow " replacement of this rock, have contributed, but it seems probable that both processes have been active.

It is evident from the close association of manganiferous and non-manganiferous types, that the same interpretation must apply also to a large number of deposits of the latter type.

One characteristic variety of non-manganiferous skarn ores presents an entirely different picture. This is the type with highly magnesian skarn (mostly humite minerals, forsterite or serpentine) and that only in moderate quantities. This type, which is related to the dolomite or limestone in a way very clearly indicating replacement, provides, in this region, the only unquestionable evidence of iron ores that have resulted from contact metasomatism. For many other types, with skarn of diopside, tremolite, etc., such an origin is probable or at least possible, but it is only the extremely magnesian variety that presents unequivocal evidence, in the occasional but very characteristic appearance of borates typical of contact deposits (ludwigite, fluoborite, szaibelyite).

From a genetic point of view, therefore, one may distinguish between two kinds of skarn ores, those with reaction skarn, and those with primary skarn. The former, probably a quite decided majority of the deposits, originated as sediments or through replacement at comparatively shallow depths, during the accumulation of the leptite series. The metamorphism indicated by the reaction skarns is, for very strong reasons, believed to have taken place during the deformation of the leptite series and the intrusion of the first granite group. Many cases are known where it can be shown clearly that the skarn-forming reactions preceded the regional magnesia metasomatism which was allied to the granite intrusion. Thus changes meaning an increase of magnesium relative to calcium occurred in the skarn, for instance replacement of hedenbergitic diopside by tremolite or anthophyllite, the iron set free forming a new generation of magnetite. Since the plainly pyrometasomatic type of skarn ore is also genetically connected with the first granite group, the development of skarn may be regarded, in all its phases, as the result of processes connected with the folding of the leptite series and the intrusion of the first group of granites: first, reaction skarns were formed; later, the skarn-bearing deposits were in many cases " worked over " by solutions that added magnesia (and occasionally some iron), and in places limestones or dolomites were replaced by pyrometasomatic deposits, the skarn of which is to be designated as primary. With such a complicated history, it is hardly surprising that for many individual deposits it has not proved possible to establish the exact part played in their development by the various processes. One has to be satisfied with the knowledge that these processes have been at work in the region, and that in very many cases one can be fairly sure of their relative importance.

The same general considerations apply to the limestone ores, but it seems fairly certain that among them the pyrometasomatic origin is represented only by few and insignificant occurrences.

As to the third type of iron ore recognized in Central Sweden, the apatitic ores, it is evident that it originated in essentially the same way as the analogous deposits in northernmost Sweden, such as those at Kiruna. This means that the apatitic ores are magmatic products, showing intrusive relations to their wall rocks. But the study of this type has not contributed anything that allows an analysis of their development more detailed than the general picture earlier obtained from the examination of their more northern counterparts.

Over wide parts of the ore-bearing region, the character of the deposits to-day is without doubt exactly as it was at the end of the first epoch of granite intrusions. However, in other parts, and particularly in some wide border zones, the second granite invasion has brought about considerable changes in the ores and still more in the rocks of the leptite series, while the effects upon the earlier granites are much less pronounced. The younger granites are cross-cutting, often accompanied by great quantities of pegmatites—which are never found in genetic connection with the earlier granites—and over wide areas form part of a migmatizing process. Where these effects are least pronounced, the leptites may be partially transformed into mica-schists, while the granites and pegmatites exhibit ordinary intrusion phenomena. In the regions of migmatitization, however, the leptites are turned into veined, streaky gneisses, pegmatite intrusions take on the character of *lit-par-lit* injections, and mobilization of material contained in the ores and rocks may lead to intimate mixtures of the old elements and granitic magma.

The last group of Archaean granites of the region, the Gothian granites, is only rarely in contact with the iron ores and then causes local metamorphism which may include re-arrangements in the skarn ores, some magnetite being consumed to form more iron-rich skarn silicates, thus reversing the results of the magnesia metasomatism.

Of the post-Archean history of the ores we know very little indeed. The very long continental history of the region, before the events of the Ice Age, can now be traced only in those few deposits, where pre-Glacial weathering had gone down to unusual depths, so that its " roots " have been spared by erosion in Glacial and earlier times. The best cases are certain limestone and skarn ores, changed to a mixture of limonite and martite, and passing downwards, through a zone of decreasing martitization, into unaltered magnetite ore. It has been found that the limonite, or at least most of it, originated from the oxidation of secondary siderite. This siderite apparently indicates a downward transport of iron from the upper parts of the ore bodies, where weathering under reducing conditions had dissolved iron; later, surface waters percolating downwards more or less completely oxidized the siderite to limonite, and the remaining magnetite to martite. As to the time when these different kinds of weathering were active we only know that both were later than late Pre-Cambrian diabase dykes, and earlier than the last glaciation.

LA NOTION DE TEMPS EN GÉOLOGIE ET LA TECTONIQUE D'ÉCOULEMENT PAR GRAVITÉ

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RÉSUMÉ

Cette théorie a été admise à la fois par les géologues alpins (nappes de charriage) et par les géophysiciens (calcul de la viscosité de l'écorce terrestre); comparaison avec l'écoulement des glaciers; critique des " Reliefüberschiebungen "; théorie des modèles réduits appliquée au soulèvement postglaciaire scandinave.

Si les roches sialiques peuvent couler en surface par gravité, elles ne peuvent devenir rigides dans le tréfond (" serres " d'E. Argand). Donc les zones isoclinales (dites zones de racines de nappes) sont des zones, non de compression, mais de succion (Verschluckungszonen, underthrusting). Les orogènes sont des zones de bouillonnement, avec courants de convection descendants (succions) et ascendants (intumescences, aux flancs desquelles les plis et nappes s'écoulent par gravité).

En résumé, les phénomènes orogéniques s'expliqueraient par trois mécanismes moteurs: (*a*) l'écoulement par gravité pour la tectonique superficielle, (*b*) les courants de convection, et (*c*) les réajustements isostatiques pour la tectonique profonde).

En Europe, ce sont des tectoniciens alpins (suisses, italiens, autrichiens, français) qui, par l'observation des détails de structure de nos montagnes, ont été conduits à cette théorie. Pendant ce temps, en Amérique surtout, et d'une façon tout à fait indépendante, on arrivait à cette même notion d' " écoulement des roches par gravité " par des considérations géophysiques théoriques, en cherchant à réaliser ou à imaginer les phénomènes orogéniques en " modèles réduits " mathématiquement calculés, et en évaluant ainsi la " rigidité " de l'écorce terrestre (Hubbert, 1945). Le moment est venu de confronter ces deux points de vue qui, totalement différents dans leur principe, viennent aboutir à des conclusions identiques.

I. LE POINT DE VUE DES TECTONICIENS ALPINS

Dans les anciennes théories tectoniques, aussi bien celle de la " contraction du noyau terrestre " que celle des " dérives continentales," les moteurs responsables des plissements de nos montagnes restaient toujours des " poussées latérales," tangentielles, exercées par certains compartiments de l'écorce, qualifiés de " rigides " (les blocs continentaux, ou les " serres "), sur les compartiments voisins, qualifiés de " souples " (les géosynclinaux, ou orogènes).

Mais déjà, pour décrire les détails de cette " tectonique souple," plis et nappes de charriage, on usait du " langage de l'écoulement "; déjà E. Argand avait parlé de " flux." Et les jeunes tectoniciens alpins attiraient l'attention sur un point de vue un peu négligé par E. Argand et plus encore par P. Termier, celui de la différence de plasticité, de capacité d'écoulement, des diverses assises superposées dans ces plis ou nappes; c'est ce que j'ai appelé la " tectonique d'écoulement différentiel." Le style des nappes helvétiques de la Suisse orientale (Helbling, 1938) et celui des nappes sub-briançonnaises en France (Barbier, 1946) étaient expliqués par la plasticité différente des couches affectées par le déclanchement de ces nappes; et la clef de l'architecture alpine était fournie par la reconnaissance de grandes " zones de décollement."

Mais en même temps, comment ne pas voir que s'affirmait de plus en plus une contradiction entre la notion d'écoulement, de plasticité, et celle d'une poussée latérale s'exerçant à l'origine, à la " racine " de ces nappes et en assurant la progression? Comment comprendre que les nappes préalpines, simples pellicules, épaisses de 2 à 3 km. au plus, et longues de 50 km. au moins, aient pu avancer sous l'action d'une " poussée tangentielle," d'une *vis a tergo*, appliquée à leur origine, à leur racine?

Cette contradiction était apparue, avec une clarté aveuglante, à tous les géologues français qui étudiaient les nappes du Flysch de l'Embrunais-Ubaye, et en particulier à D. Schneegans (1938), puis à L. Moret (1937) et à moi-même (Gignoux, 1939, 1942; Gignoux et Moret, 1938). Cette nappe est formée par l'écoulement vers l'Ouest, sur 20 ou 30 km., du Flysch tertiaire qui constituait primitivement la couverture du Mésozoïque de la zone, plus orientale, du Briançonnais. Ce Flysch est un matériau éminemment plastique; sa base, surtout, est argileuse (Flysch noir) et a facilité l'écoulement; et sa masse principale est formée de multiples alternances de bancs schisteux et gréseux, épais de quelques centimètres ou décimètres, empilés sur plus de 1.000 m. d'épaisseur. C'est d'autre part l'assise la plus récente que nous connaissions dans ces zones alpines internes; elle n'a jamais été surmontée d'aucune couverture formant surcharge, d'aucun " traineau écraseur " (P. Termier). Or, dans la nappe, ces bancs n'apparaissent nullement laminés, mais affectés de multiples plissottements, avec des charnières régulières (structure fluidale), couchées jusqu'à l'horizontale (Gignoux 1948a; voir la pl. phot.).

Pour comprendre, c'est à dire pour nous représenter en modèle réduit, la progression de cette nappe du Flysch, nous sommes conduits à la comparer à l'écoulement d'une flaque de miel étalée sur une table, et dont on pousserait l'un des bords (ici la " racine " de la nappe) avec une raclette. Mais alors, ce qui fait avancer l'autre bord (le " front ") de la flaque de miel, ce n'est point la " poussée " de la raclette, c'est l' " intumescence," le gonflement produit par cette poussée, gonflement qui fait écouler progressivement, par gravité, toute l'étendue de la flaque.

Mieux encore, nous pourrions supposer que notre flaque de miel s'est écoulée sur une table recouverte d'une toile cirée. Alors, pour faire écouler le miel, nous pouvons introduire une petite réglette entre la table et la toile cirée et la faire avancer progressivement; l' " onde d'intumescence " (voir plus loin) que nous ferons ainsi progresser pourra provoquer de proche en proche l'écoulement de tout le miel sur une grande distance, sans que jamais notre intumescence ait été très haute: c'est ainsi que nous pouvons expliquer la grande amplitude des charriages alpins.

Ainsi, par la seule observation et par des intuitions et comparaisons grossières, nous arrivions à cette conclusion que seule la gravité pouvait être le moteur responsable de l'avancée des nappes alpines. C'est à cette notion que se sont ralliés un très grand nombre de tectoniciens des Alpes, de l'Apennin (Dal Piaz, 1942; Trevisan, 1946) et du Maroc (Lacoste, 1940). Mais beaucoup d'entre eux l'ont mal comprise ou n'ont pas osé en tirer toutes les conséquences qui en découlent.

On nous objectera d'abord que, si les roches pouvaient couler sous la seule action de la gravité, les vallées devraient se combler continuellement par l'écoulement de leurs versants et ne pourraient subsister. Pour répondre à cette vieille objection, déjà faite à Haarmann, remarquons que les plissements et écoulements des roches d'une part, le creusement des vallées d'autre part, sont des phénomènes, l'un " orogénique " (dynamique interne), l'autre " géographique " (dynamique externe), qui se déroulent à des échelles de temps très différentes. Je suis de ceux qui admettent que le creusement des vallées les plus profondes des Alpes peut être entièrement l'oeuvre des érosions quaternaires; car les surfaces pliocènes, quand nous les suivons jusqu'en bordure de la chaîne, se prolongeraient certainement au-dessus des plus hauts sommets. Or nous connaissons bien des dépôts quaternaires inclinés et déformés, et même ondulés, mais nulle part les roches dures quaternaires (ni même pliocènes) n'ont eu le temps, par écoulement, d'acquérir dans leur intimité une structure vraiment plissée ou plissottée, à l'échelle du mètre ou du décimètre, comme le Flysch tertiaire de nos Alpes.* Pour nous aider à comprendre comment se superposent ces deux catégories de phénomènes, orogéniques et morphologiques, nous n'avons qu'à évoquer l'exemple des glaciers (Chamberlin, 1928; Gignoux, 1948b): un glacier s'écoule dans sa masse, comme un fleuve liquide (mais environ 100.000 fois moins vite); et en même temps sa

* Par contre, un sédiment quaternaire peut être faillé; mais c'est là de la " tectonique de choc " (Maillet, 1937), que nous n'étudierons pas ici et qui se déroule, par petites secousses discontinues, à une vitesse infiniment plus grande que la tectonique d'écoulement, lente et continue. Mais peut-être cette apparente continuité de l'écoulement est-elle faite en réalité d'une infinité de discontinuités élémentaires (quanta), comme l'écoulement des glaciers (Chamberlin, 1928; Gignoux, 1948b), et comme l'écoulement des métaux (Andrade, 1947).

surface reste accidentée et creusée de vallées et de rigoles entaillées par les ruisseaux qui y circulent.

Ainsi il n'y a en principe aucune relation entre le modelé superficiel dû à l'érosion, et la formation des plis et la progression des nappes. Pour bien apprécier les rapports des phénomènes géographiques d'une part, orogéniques d'autre part, il faut se placer dans des échelles de temps formidablement différentes. C'est faute d'avoir bien compris cette condition préalable que certains tectoniciens alpins ont pu dire, par exemple, que les nappes préalpines s'étaient avancées en s'écoulant dans des vallées d'érosion préexistantes*: ils attribuent ainsi aux nappes une " vertu ambulatoire " spéciale (la *vis a tergo* des anciennes théories) et ils leur donnent la permission de couler, alors que cette même permission est refusée par eux aux versants des vallées, pourtant formés souvent des mêmes roches (par exemple Flysch autochtone et Flysch charrié).

De même d'autres géologues ont confondu les vrais écoulements orogéniques, générateurs de plissements, avec des glissements ou écroulements de masses rocheuses (pans calcaires, par ex.) le long de talus argileux préalablement modelés par l'érosion (exemples cités: Gignoux, 1948a). Ces écroulements superficiels très rapides sont bien dus à la gravité; mais ils ne font que " singer " les véritables phénomènes orogéniques; ils sont comparables aux chutes de séracs dans les glaciers.

II. LE POINT DE VUE DES INGÉNIEURS QUI ÉTUDIENT LA RÉSISTANCE DES MATÉRIAUX

Notre problème essentiel est de savoir si, sous l'action de contraintes aussi faibles que celles de leur propre poids, les roches solides de l'écorce terrestre sont susceptibles de se déformer et de s'écouler. Ainsi posé, ce problème parait rentrer dans le domaine expérimental des ingénieurs qui étudient la " résistance des matériaux." Et il est traité avec beaucoup de compétence par l'ingénieur (qui est en même temps un géologue), J. Goguel, dans un important mémoire (1943), devenu classique, où il expose les résultats des expériences récentes des savants américains (Griggs, 1939) et des siennes propres sur la capacité de déformation des roches dures. Si, pendant la durée d'une expérience de laboratoire (quelques semaines, mois ou années), on veut voir une éprouvette de roche dure se déformer et se raccourcir (c'est à dire atteindre le " seuil de plasticité " bien avant le " seuil de rupture "), il faut la soumettre à une pression orientée de l'ordre de 5.000 kgs/c^2, et ceci sous une pression générale (confining) de l'ordre de 1.600 kgs/c^2; on arrive alors à un raccourcissement de l'ordre de 10 pour cent.

Mais, comme le fait remarquer J. Goguel, de telles pressions ne sont jamais réalisées par le seul champ de gravité dans les zones relativement superficielles de l'écorce terrestre où nous voyons se produire les plissements et les nappes de charriage; nous savons aussi que la plasticité des roches augmente avec la température; mais nous savons aussi que les roches plissées de beaucoup de nos nappes alpines ne se sont jamais trouvées à haute température.

La réponse de J. Goguel est donc formelle: les roches dures (calcaires, grès, granites) sont incapables de se déformer et de s'écouler sous des contraintes (pressions différentielles) de l'ordre de grandeur de celles qui sont mises en jeu par la seule gravité dans les couches superficielles de l'écorce terrestre.

Mais ces expériences et ces calculs ne valent que si on se place à l'échelle de temps de l'ingénieur-expérimentateur, par exemple entre le dixième de seconde et la dizaine d'années. Car si on change l'échelle de temps, les propriétés physiques d'un même matériau, et par conséquent les formules mathématiques à lui appliquer, vont changer en même temps. Ainsi le caoutchouc, vu à l'échelle de temps de la vie ordinaire, celle de l'ingénieur, est un corps solide qui se déforme par élasticité; vu avec une unité de temps suffisamment brève, il nous apparaîtra comme un corps solide que l'on pourrait briser à coups de marteau (à condition que ce coup de marteau soit donné avec une vitesse prodigieuse); enfin ce même caoutchouc, vu à l'échelle des temps géologiques, ne sera plus ni rigide, ni élastique, mais se déformera par viscosité et écoulement. Citons encore la cire à cacheter (sealing wax) (exemple déjà évoqué par Wegener), qui se comporte comme un solide brisant dans des expériences ne durant

* C'est la notion déjà ancienne des *Reliefüberschiebungen*, ou charriages en relation avec les formes topographiques; tout récemment, M. Richter (*Geol. Rundschau*, 35, 2, 1948, p. 166) vient de décrire dans les Alpes orientales l'exemple le plus grandiose, dit-il, de Reliefüberschiebung dans toute la chaîne alpine.

que quelques heures, mais qui se déforme et coule sous l'action de son poids au bout de quelques semaines. Au reste les études modernes sur l'écoulement des métaux (Da Andrade, 1947) nous ont montré qu'il n'y avait pas de frontière nette entre solide, visqueux et liquide.*

Ainsi, en nous plaçant à l'échelle des temps géologiques (que nous préciserons tout à l'heure), les notions de seuil de plasticité, de seuil de rupture, s'évanouissent; et nous n'avons plus le droit d'appliquer aux roches les résultats numériques que nous fournissent les ingénieurs qui étudient la " résistance des matériaux."

III. LE POINT DE VUE DES INGÉNIEURS QUI CONSTRUISENT DES " MODÈLES RÉDUITS "

Un Physicien qui raisonne sur la constitution de la matière (Physique corpusculaire) se représente cette matière en " modèle agrandi," où les atomes, noyaux, électrons, etc. sont figurés par de petites boules. Inversement un astronome se représentera un " modèle réduit " de l'univers planétaire, où les astres seront aussi figurés par de petites boules. De même un géologue qui raisonne sur les phénomènes orogéniques a forcément devant les yeux un " modèle réduit": il le réalise en dessinant des coupes géologiques: ainsi il étudie la " statique " des plissements. Il peut aussi le réaliser en dessins animés: c'est ce qu'a fait L. Moret (1937) dans un film consacré à l'histoire géologique des Alpes françaises†: c'est un modèle réduit cinématique.

Mais pour étudier la dynamique des plis et des nappes, il faut nécessairement construire (ou imaginer) un modèle en une matière susceptible d'être déformée plastiquement. C'est ce qu'ont fait les nombreux géologues qui, depuis Daubrée, ont tenté des essais de " tectonique expérimentale " (Cloos, 1936). Ils ont d'abord employé des matériaux solides (argiles, cires, paraffines, etc.) juste assez plastiques pour pouvoir être déformés, au besoin sous des surcharges, par des compressions latérales, les " poussées tangentielles " des anciennes théories tectoniques, sans se préoccuper de calculer exactement les propriétés physiques de ces matériaux. Mais un tel calcul est maintenant familier aux ingénieurs qui, pour leurs constructions (par exemple les grands barrages de retenue, les avions) réalisent aussi des modèles réduits.

Bien entendu, comme me l'a fait aimablement remarquer J. Goguel (*in litt.*), ces formules de transformations d'unités nous permettent seulement de calculer les caractéristiques physiques (ici la viscosité ou capacité d'écoulement) du modèle en fonction de celles de l'objet réel (ici les roches), ou inversement. Nous pourrons donc, ou bien imaginer (ou réaliser) un modèle que nous jugerons (ou que nous constaterons) capable de reproduire les phénomènes orogéniques, et en déduire les caractéristiques des roches, ou bien calculer directement ces caractéristiques (et en déduire celles du modèle) en partant d'un phénomène orogénique naturel sur lequel nous avons des précisions numériques suffisantes (en particulier la durée): c'est ce qu'ont fait M. King Hubbert et les géophysiciens finno-scandinaves (voir plus loin).

En France, ces méthodes de calcul ont été appliquées pour la première fois à l'étude des phénomènes orogéniques par R. Maillet, F. Blondel et R. Pavans de Ceccaty (1934, 1937). Ils concluent que si l'on veut reproduire (ou imaginer) sur un modèle de laboratoire, en 10 ans, la formation d'une chaîne de montagnes qui a duré un million d'années, le matériau à employer doit être comparable à une " pâte dentifrice (toothpaste) diluée"; ainsi, disent-ils, " un tel matériau s'écoulerait sous la seule action de son poids; il ne pourrait transmettre de poussées"; c'est donc bien la théorie de l'écoulement par gravité qui seule peut expliquer la formation des plis et nappes de charriage: ainsi se justifie l'image de la flaque de miel que nous évoquions au début.

L'article des ingénieurs français parait être resté ignoré en Amérique, où pourtant le même problème a fait l'objet des études très intéressantes de D. Griggs (1939) et de M. King Hubbert (1945). Le

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* L'étude de la déformation des solides est maintenant réunie à la Mécanique des Fluides sous le nom de " Rhéologie": *Essays in Rheology, a contribution to the literature of a new science, based on the* 1944 *Oxford Conference of the British Rheologists' Club* (Sir Isaac Pitman & Sons, London, 1947).

† Ce film a été projeté pendant quelques années au Palais de la Découverte à Paris; il donnait une impression saisissante d' " écoulement par gravité "; mais il est actuellement devenu inutilisable et le négatif a été égaré pendant la guerre.

premier, pour son ingénieuse étude expérimentale des courants de convection (voir plus loin), a réalisé ses modèles en employant des matériaux tels que des solutions de silicate de soude (waterglass), des huiles de graissage, des glycérines. Enfin M. King Hubbert a fait de la question un long exposé très clair et très " populaire," dont la lecture se recommande spécialement aux géologues non physiciens. Il a appliqué la théorie des modèles réduits à l'étude d'un exemple précis, le soulèvement postglaciaire du bouclier finno-scandinave, pour lequel les géologues finnois nous ont apporté des caractéristiques numériques précises. Par une curieuse rencontre avec les ingénieurs français, il conclut que le matériau à employer pour le modèle réduit imaginé par lui devrait être comparable à une " toothpaste " (pâte dentifrice) ou à une solution de silicate de soude (water-glass) de viscosité d'environ 10^6 poises.* Enfin, remontant du modèle à l'objet, il évalue la viscosité moyenne de l'écorce terrestre dans la région intéressée à 10^{22} poises, résultat comparable à celui obtenu par les géophysiciens scandinaves, par calcul direct.

Et cette valeur numérique lui permet d'aborder par le calcul le problème de l'écoulement des roches par gravité, par simple application des lois mathématiques de l'écoulement d'un fluide dont on connait la viscosité. Il considère donc une tranche horizontale de roche dure affleurant à la base d'une falaise verticale de 370 m. de haut (je reproduis telles quelles ses données numériques). Sous la surcharge des roches qui la surmontent, l'épaisseur de cette couche se réduira, par écoulement latéral, de un millionième en 10 ans (valeur totalement inappréciable par des expériences de laboratoire) ou de un dixième en un million d'années.

Ainsi, en adoptant comme unité de temps le million d'années, nous verrions les roches les plus dures de l'écorce terrestre superficielle couler comme des fluides visqueux sous la seule action de la gravité. Or, le million d'années est précisément l'unité de temps que les géologues ont été conduits à adopter quand ils veulent évaluer la durée de formation d'une chaîne de montagnes: c'est l'unité de temps orogénique.

IV. LA TECTONIQUE PROFONDE: LES INTUMESCENCES, LES ZONES DE SUCCION, LES COURANTS DE CONVECTION

Ainsi beaucoup de tectoniciens alpins admettent maintenant la théorie de l'écoulement par gravité et reconnaissent avec quelle facilité et quelle souplesse cette théorie se prête à l'explication de toutes les particularités de structure des nappes alpines et apennines; je n'y insiste donc pas. Mais, chose curieuse, il semble que l'immense majorité des géologues, subitement et superficiellement convertis à la tectonique nouvelle, hésitent encore à en accepter toutes les conséquences.

Ils admettent bien que les nappes alpines ont coulé comme une pâte dentifrice, mais ils se représentent que, dans la région des " racines " de ces nappes, cette pâte devait déborder d'une sorte de " tube " comprimé dans un étau; elle n'aurait coulé qu'après avoir débordé. Ils ne se résignent donc point à abandonner une des notions fondamentales de l'ancienne tectonique argandienne, celle des " serres " ou gigantesques blocs rigides qui agissaient, soit comme des mâchoires d'étau (ex., l'Europe et l'Afrique enserrant les chaînes méditerranéennes), soit comme des proues de navires, dont la progression déclanche un cortège de vagues qui les précèdent (cf. les " chaînes de proue " d'E. Argand, les cordillères pacifiques américaines).

Mais comment admettre que la roûte superficielle de roches sialiques peut s'écouler par gravité dans les plis et les nappes (tectonique superficielle), alors que dans les régions de racines isoclinales (tectonique profonde) ces mêmes roches deviendraient rigides et n'auraient plus la permission de couler? D'abord ce contraste n'est pas confirmé par l'observation. La vieille distinction classique entre socle rigide et couverture souple résulte simplement de l'existence d'une " zone de décollement " entre socle et couverture (voir R. Barbier, 1946); elle ne s'applique que dans les zones bordières des intumescences orogéniques, dans le domaine de la tectonique superficielle d'écoulement (différentiel) par gravité. Mais quand nous pénétrons au coeur même des orogènes, nous voyons ces mêmes roches

* Pour fixer les idées, rappelons que la viscosité 1 correspond à celle d'une huile de graissage; la viscosité d'un miel est de 40 poises, celle d'un asphalte de 6×10^6 poises, et celle de l'eau à 15° de 10^{-2} poises.

anciennes (ex., les amphibolites et gneiss du Cervin et de la Dent-Blanche) nous montrer une tectonique souple d'écoulement.

Evidemment, le moteur de cette tectonique profonde ne peut plus être la gravité. Et les géophysiciens semblent maintenant unanimes à admettre que ce moteur ne peut être fourni que par des phénomènes de convection (dont ils ne savent d'ailleurs préciser la nature, flux thermiques, transformations radioactives?), se traduisant par des courants de convection (D. Griggs, 1939).*

Nos orogènes deviennent ainsi des " zones de bouillonnements " (Gignoux, 1939). Les courants ascendants s'y traduiront par des intumescences, sur les flancs desquelles les plis et les nappes s'écouleront en surface par gravité (Haarmann, 1930). Dans les Alpes françaises, c'est une telle " ond-d'intumescence " (Gignoux, 1948a, p. 25) qui s'est avancée progressivement de l'Est à l'Ouest, du Briançonnais au front externe subalpin, où elle arrive aujourd'hui, après avoir déclanché successivement les nappes (oligocènes) du Briançonnais et de l'Embrunais et les plis (postmiocènes) subalpins. Les courants descendants se traduiront par des " zones de succion," isoclinales (zones dites de " racines de nappes "), marquées par des lignes d'anomalies négatives de la gravité (Niggli, 1947; Umbgrove, 1948a); nous y retrouvons à la fois la vieille notion des " Verschluckungszonen " (zones d'engloutissements) d'O. Ampferer (qui, chose remarquable, y avait été conduit par ses seules observations de géologue, et non par la Géophysique) et la notion moderne des " boucles orogéniques " de Vening Meinesz et d'Umbgrove (1945, 1948 a et b).

Enfin les études récentes sur les chaînes en arc des Indes orientales (Umbgrove, 1945; Vening Meinesz, 1940) nous ont montré les relations existant entre les " zones de succion " et les séismes profonds: ces derniers se produisent le long des surfaces listriques (E. Suess) qui marquent les contacts entre courants de convection ascendants et descendants et servent également de voies d'accès aux injections des magmas simiques. Dans les Alpes françaises, nous pourrions ainsi préciser les idées un peu audacieuses développées par J. Rothé.† Les lignes de séismes profonds, de faible intensité, mais de grande extension se traduiraient en surface par deux zones de succion, l'une dans le Briançonnais, dans la région des racines des nappes préalpines et subbriançonnaises, l'autre suivant la limite alpino-dinarique: ce serait de la tectonique de choc profonde. Au contraire les séismes superficiels, très violents mais très localisés, se produisent au front des écoulements actuels, c'est à dire sur le bord externe des chaînes subalpines (séismes récents de Nice, d'Aix-en-Provence, du Tricastin): ce seraient des manifestations d'une tectonique de choc superficielle, dues aux phénomènes d'écoulement par gravité, et non aux courants de convection profonds.

Finalement, quand les courants de convection se calment, c'est, comme l'a si bien montré D. Griggs, un troisième moteur qui entre en jeu: le réajustement isostatique, qui provoque la remontée des tréfonds sialiques légers (" roots "), auparavant succés en profondeur par les courants de convection.

Dans toutes ces théories, les géophysiciens, bien qu'usant de formules mathématiques, se sont montrés bien plus audacieux et plus intuitifs que les géologues de surface. Dans cet article, nous avons essayé de faire le pont entre ces deux points de vue. Il faut que les géophysiciens, comme les géologues, s'habituent à mieux réaliser l'immensité des temps géologiques et se rappellent que les propriétés physiques de la matière changent avec l'échelle de temps à laquelle on la considère. Les physiciens et les ingénieurs ne s'occupent de la matière que pour la maîtriser et en construire des machines destinées à fonctionner dans l'échelle de temps de la vie ordinaire; mais quand ils veulent expliquer le lointain passé de l'Univers, cette " machine à faire des dieux " (Bergson), ils sont obligés de changer d'échelle de temps et d'apprendre à " penser en géologues."

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* La théorie de Griggs est excellemment résumée dans A. Holmes, Principles of Physical Geology.

† Ann. Inst. Phys. du Globe Univ. Strasbourg, 3, 3e partie, Géophys., 1938-1941.

PART XIII: OTHER SUBJECTS

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MOUNTAIN BUILDING IN THE CANADIAN PRE-CAMBRIAN SHIELD

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ABSTRACT

A review of available facts suggests that in Early Pre-Cambrian time the crust was thin, geosynclines were relatively narrow and accumulations of sediments in them relatively thin. Mountains were formed by compression and shortening of geosynclinal belts as in later times, but elevations were less and shorter lived. On the other hand, mountains were built more frequently.

Sediments classed as Late Pre-Cambrian have a different aspect, indicating a change in the destructive processes operating. Also the record suggests that geosynclines were broader and fewer and that mountain building was less frequent.

Comparison of stratigraphic sections and unconformities in widely separated areas may show similar sequences, but this does not necessarily mean that formations and unconformities similarly placed correspond closely in age.

INTRODUCTION

THIS paper gives a brief review of the broader features of the rocks and structures in the Canadian Shield and interpretations relating to mountain building that have developed in the writer's mind over the years through contact with various parts of the field, the geologists active in it and their writings. As is bound to be the case, much of what follows is not original. However, it is hoped that enough of it is new to make it interesting to members of the Congress and to stimulate further investigation of the extremely interesting, though complex, problems touched upon.

GENERAL DESCRIPTION OF THE SHIELD

Location and Area.—The Canadian Pre-Cambrian Shield is an area of 1,790,000 square miles around Hudson Bay in north-eastern Canada where the bedrock exposed is almost entirely of Pre-Cambrian age. Extensions of it are found in Greenland and the United States, giving a total area of Pre-Cambrian rocks of approximately 2,800,000 square miles.

Investigations to Date.—This area has been under study since 1845, when Sir William Logan started his investigations for the Geological Survey of Canada. During the early years of the Survey, reconnaissance surveys were extended widely throughout the Shield under extremely difficult conditions; then with the discovery of the important ore deposits at Sudbury, Cobalt, Porcupine and Kirkland Lake, more detailed and systematic work was undertaken and extended over wider and wider areas. In recent years surveys on a scale of 1: 12,000 or larger have been carried out in some of the mining areas and, as a result, the structural and age relations of the rock formations are now, for the first time, being firmly established. Top determinations by grain gradation, cross-bedding, pillow forms and other methods have played an important part in this new work. There is a growing mass of information significant in relation to the broader problems of early earth history to be found in the publications of the Geological Survey of Canada, the Ontario Department of Mines and the Quebec Department of Mines. Much precise work is also being done by geologists working for mining companies. Some of their results are published from time to time in the journals devoted to Mining and Geology, but much of it is, unfortunately, locked up in files. An important contribution is the forthcoming Symposium Volume on the Structural Geology of Canadian Ore Deposits, arranged and published by the Canadian Institute of Mining and Metallurgy.

Most of the work done to date has been around the outer margin of the Shield and particularly in its southern part. Even in the most studied sections knowledge of it is far from complete, though it has been advanced far beyond what was dreamed possible by the early workers. The more remote northern parts are still practically unknown. Considering the mainland portion of the Shield, approximately 15 per cent has been covered by reconnaissance surveys, less than 1 per cent has been mapped at 1 mile to an inch or larger. This 1 per cent is, however, in strategic localities and much more is known of the geological history of the area than these figures would indicate. It must be remembered also that much more has been seen by workers in the area than appears on maps. Further details relating to mapping in Canada will be found in a paper by Chipman and Hanson (1944).

General Character of the Bedrock.—The great bulk of the exposed rock is composed of granitic intrusive masses and medium to high grade metamorphic rocks, but these areas have been least studied of all. Only in a few areas have maps been made showing a separation between granite and gneisses.

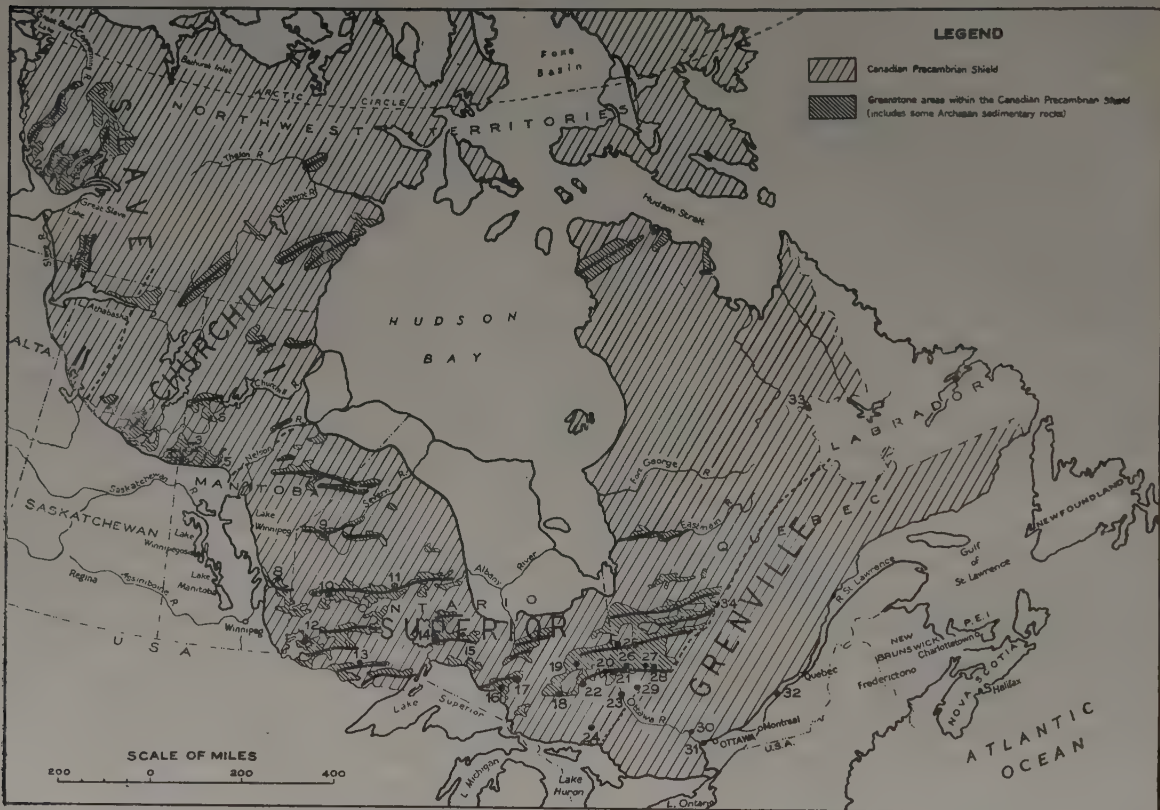

FIG. 1.—*Map showing structural trends in Archean formations and a suggested division of the Canadian Pre-Cambrian Shield into Provinces.*

Index to Mines or Mining Areas:—

1. Eldorado.
2. Yellowknife.
3. Sherritt-Gordon.
4. Flin-Flon.
5. Nor-Acme.
6. Lynn Lake.
7. Gods Lake.
8. San Antonio.
9. Berens River.
10. Red Lake.
11. Pickle Lake.
12. Wendigo.
13. Steep Rock Iron.
14. Sturgeon River.
15. Little Long Lac.
16. Michipicoten.
17. Gondreau.
18. Jerome.
19. Porcupine.
20. Kirkland Lake.
21. Larder Lake.
22. Matachewan.
23. Cobalt.
24. Sudbury.
25. Normetal.
26. Noranda-Rouyn.
27. Cadillac-Malartic.
28. Val d'Or.
29. Belleterre.
30. New Calumet.
31. Kingdon Mine.
32. Tetrault.
33. Ferriman Falls.
34. Chibougamau.

Scattered patches of little-metamorphosed volcanics and sediments have received most of the attention to date. The distribution of those that have been mapped is given in Fig. 1. They range in size from a few square miles to 30,000 square miles in area. The largest continuous areas of these rocks occur to the south of James Bay and north-east of Great Slave Lake. These larger areas are penetrated at intervals by granite batholiths and are surrounded by granitic intrusives, as are the smaller ones.

Perhaps the most surprising feature of the Shield as a whole is the highly deformed character of most of the rock. It is rare to find undeformed strata in the Shield. Those that do occur are all clearly of Late Pre-Cambrian age and most of them are in the western marginal parts, indicating that the central and eastern parts stood relatively high, probable until Ordovician time (Richmond) when the Hudson Bay basin was depressed below sea-level.

Fold systems with trends persistent over tens or hundreds of miles are discernible in most parts of the Shield. They are generally better defined in the least metamorphosed areas. In gneiss areas the regional trend is obscured by innumerable local small and medium-scale structures of an aberrant and local type, often involving thickening and thinning of layers and other features characteristic of plastic deformation. Clearly they have been, at one stage, in a condition where small stress differences of a persistent type have caused them to yield.

Early Pre-Cambrian and Late Pre-Cambrian Series.—In those parts of the Shield where sediments and volcanics are preserved these rocks fall naturally into two groups, an older one commonly referred to as Archean, Archeozoic or Early Pre-Cambrian, marked by conglomerates, arkose, greywacke and minor amounts of argillite, slate and lean iron-bearing formation, and a younger one, Proterozoic or Late Pre-Cambrian, marked by quartzite, dolomite, limestone, slate and variable amounts of greywacke, arkose, conglomerate and iron-bearing formation. The absence of clean quartzite and limestones from the older series is particularly noteworthy.

The distinctions mentioned have been noted repeatedly in descriptions of particular areas, but only since mapping has been extended widely over the Shield has it been realized that this is a general condition. It is a most interesting and no doubt a most significant one.

The Archean lavas and sediments are widespread, as can be seen in Fig. 1, and deformation, commonly close folding and faulting, is found throughout all the preserved remnants. The lavas are dominantly of basic or intermediate types though acid types occur. The conglomerates contain pebbles and boulders of lavas and a variety of igneous intrusive rocks including granite, showing that plutonic types had been exposed by erosion at the time of their deposition.

Lacking fossils, attempts at correlation of separate patches of lavas and sediments have necessarily been based on lithologic similarity, and comparison of sequences of sedimentation, folding and faulting, igneous intrusion and erosion. This has led to many errors, as has become apparent with the extension of detailed mapping during the last 20 years. The old classification of Early Pre-Cambrian rocks into " Keewatin " lavas and younger " Timiskaming " sediments has had to be modified sharply. It is now apparent that sediments similar to the Timiskaming series at Lake Timiskaming occur in some of the oldest rock series, interlayered with lavas, and that lavas similar to the original Keewatin at Lake of the Woods occur at various horizons in the Early Pre-Cambrian. Use of " Keewatin " or " Timiskaming " in descriptions of rocks outside of the type areas mentioned should, therefore, be taken to indicate similarity in lithology but not equivalence in age.

Unconformities occur at one or more horizons in most areas of the Early Pre-Cambrian. Estimates of their importance have ordinarily been based on the angular discordance displayed in a few outcrops. Good exposures are seldom seen over any great distances. Under these circumstances it is obvious that correlations between rock series in different parts of the larger patches can seldom be made with certainty and satisfactory correlations in detail between isolated patches separated by granite or gneiss are not possible. The best hope at present for accomplishing such correlation is through perfection of age determinations by means of radioactive minerals.

The Proterozoic rocks are less abundant and less generally deformed. In particular areas two

or more series may be recognized, separated by unconformities. Lavas are abundant in some of the youngest series, though less so, on the average, than in the Archean. Lithologic similarity and similar positions in historical sequences have been used for broad correlation, but these are at best suggestive. Here again it may be said that similar sequences of events may have occurred at different times, producing similar rock series. Correlation of the youngest series, which are undeformed or little deformed over broad areas, can be made with greater confidence.

STRUCTURE OF THE ARCHEAN ROCKS

Fig. 1 shows all the remnants of little metamorphosed sediments and volcanics that have been recognized to date. They are all folded and faulted and dominant trends are indicated by heavy lines. The south-east border (Grenville Province) contains none of these and will be discussed later. The Ungava peninsula has not been explored to any extent and may contain rocks of this group. For the rest, three distinct areas with different dominant trends can be distinguished. These may be termed the Superior Province, extending from the Grenville Province to Nelson River, the Churchill Province, extending from Nelson River to the east end of Lake Athabaska and the Slave Province, extending from Lake Athabaska northwestward. The dominant structural trends in these three provinces are east-west, north-east and north respectively. The character of the deformation is similar throughout. It is less severe in the largest remnant, south of James Bay, than in many of the smaller remnants. In some areas, early folds have been bent under conditions approaching plasticity, as north of Flin Flon (See C.G.S. maps nos. 314A, 632A, 832A, 862A) and in the Yellowknife-Beaulieu areas (Henderson, 1943).

It might be supposed that the deformation over the area occurred in three stages, each of the structural provinces marking a separate episode of sedimentation with minor warpings and erosion, followed by further sedimentation and finally a wholesale collapse and mountain building as in the younger mountain-built belts. However, there are good reasons for doubting this.

First, it may be observed that the width of the Superior belt with east-west trends is greater than any later mountain-built belt known, unless we include composite belts formed by two or more periods of mountain building, such as the Western Cordilleran System in North America.

Secondly, as Pettijohn (1943) has pointed out, conglomerates present in many of the sedimentary belts, are elongated along the strike and restricted down the dip. They are therefore to be regarded as piedmont deposits derived from nearby sources. One could imagine an area of block faulting in which lavas were poured out and rapid sedimentation of conglomerates and greywacke occurred in local basins producing the stratigraphic relations cited, but the uniform folding of the whole area in one episode so as to preserve a series of similar strips of the trough deposits is not a mechanically feasible concept. Furthermore, if it did occur, the emplacement of intrusive granite batholiths between the troughs could not be explained. Any satisfactory explanation of the relations described must include a succession of foldings of volcanics and sediments laid in a series of troughs. Presumably downwarping, loading by flows and sediments, folding and intrusion would have followed one another, as in later mountain-built belts, and this pattern must have been repeated many times. Under this concept the sequences are similar, but the formations in different folded belts are not contemporaneous; nor are the batholiths of the same age.

The changes in trend marking the three " Provinces " reflect changes in general stress conditions which governed the formation of troughs in the crust. Truncation of one by another would be evidence of age sequence, but so far work in the junction areas has not given clear evidence of this. There is a suggestion in the Flin Flon-Sherridon areas of imposition of the east-west pattern of the Superior Province over the north-east trend of the Churchill Province, indicating that the Superior folds post-date those of the Churchill Province. Relations between the Slave and Churchill folds are more obscure.

If the explanation suggested is correct, individual mountain-built belts would have been of the order of 40 to 60 miles across. The enormous outpouring of lava, the numerous closely-spaced troughs, and the restricted widths of the belts indicate that the crust of the earth was thin, relatively weak and

hence probably subject to fairly frequent and rapid deformations to form swells and troughs. The sediments poured into the troughs are dominantly coarse clastic types showing little weathering of the minerals and clearly indicating rapid accumulation. Geosynclines under such conditions would be relatively short-lived and the mountains formed by the ultimate collapse of the supporting crust would probably be less lofty than if the crust had been thicker at the start.

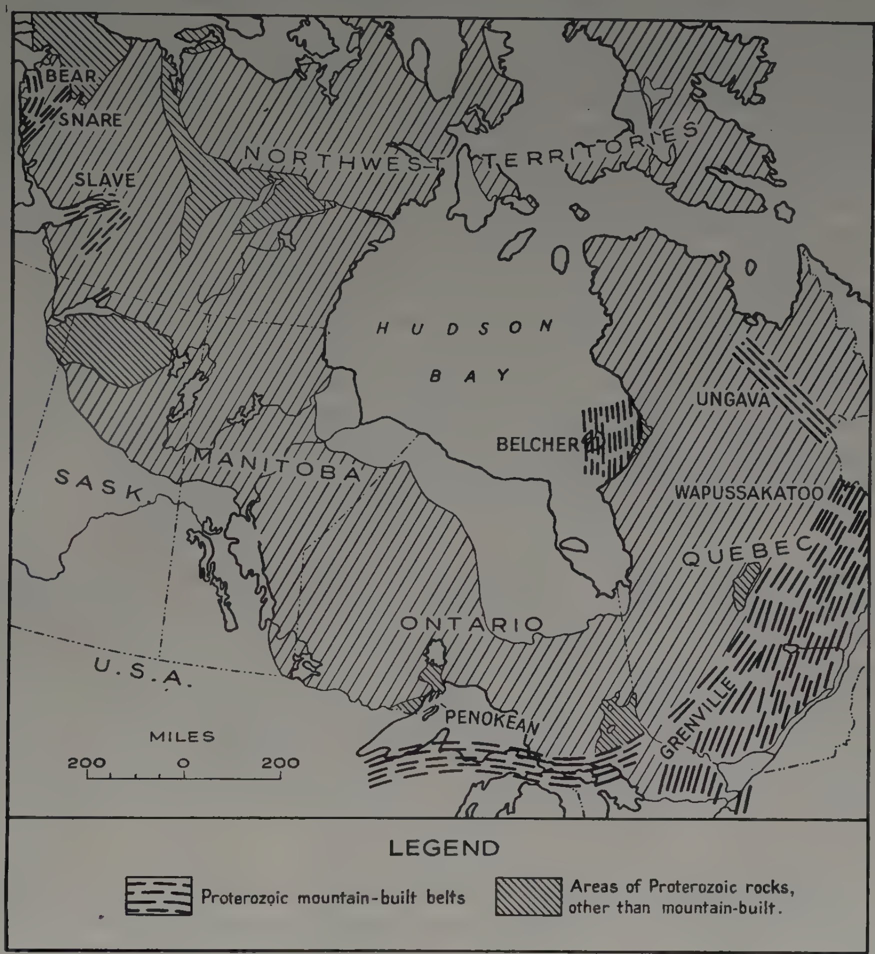

FIG. 2.—*Proterozoic rocks and mountain-built belts.*

STRUCTURE OF THE PROTEROZOIC ROCKS

In Late Pre-Cambrian time mountain building occurred only along certain widely-spaced geosynclinal troughs, the principal ones of which are shown in Fig. 2. The relative ages of the mountain building in these various belts cannot be determined at present, though various ideas have been expressed. A lower limit can be set for each in relation to the local strata by observing the youngest formations involved, but ordinarily a considerable range in time is possible upward and, in some cases, the only upward limit is set by diabase dykes, the ages of which are imperfectly known.

Penokean Belt.—Around Lake Superior and the north shore of Lake Huron is a series of Late Pre-Cambrian rocks, known as the Huronian series, consisting mainly of quartzite, dolomite, limestone, slate and iron formation. South of Lake Superior and along the north shore of Lake Huron these rocks are folded into anticlines and synclines and have been intruded by granite which, because it cuts part of the succeeding Keweenawan series (Leith, Lund and Leith, 1935, p. 20) and because

the folding which it accompanied affected at least a part of the Keweenawan sediments, is believed to be of Late Keweenawan age. Elsewhere, the undoubted Huronian rocks of this area are only mildly deformed.

The Huronian series has been divided by United States geologists into three groups known as the Lower, Middle and Upper Huronian. These divisions are based on unconformities traceable over most of the area of exposure south of Lake Superior. The structural discordances between the groups are not great and they evidently represent mild disturbances such as characteristically occur during the accumulation of sediments in a geosyncline. The main folding apparently occurred after the deposition of the Upper Huronian and it continued into the Keweenawan.

In Canada the Bruce and Cobalt " series " constitute together the *original* Huronian of Logan and Murray. They are generally believed to correspond to the Lower and Middle Huronian groups of Michigan. They are closely folded, cut by thrust faults, and profoundly metamorphosed near the Killarney granite batholith, but farther to the north the Cobalt series is only mildly deformed. The Whitewater series, which lies within the " Sudbury Basin " and is separated from the other rock series by the Sudbury lopolith, must have rested uncomformably on the other rocks before the intrusion of the norite-micropegmatite mass. It is therefore younger and has been considered to be equivalent to the Upper Huronian or Keweenawan of the United States classification. Evidently it was involved in deformation with the other rocks, though it appears to be on the margin of the deformed belt.

This Penokean mountain-built belt has been traced to an area south of Sudbury where an extensive batholith of Killarney granite separates it from the Grenville province. Faulting on a considerable scale has further obscured the relations with the rocks of the Grenville province.

OTHER LATE PRE-CAMBRIAN MOUNTAIN-BUILT BELTS

The locations of the other belts of highly folded and faulted Late Pre-Cambrian rocks are shown in Fig. 2 by dashed lines. They differ in details of rock character and deformation from one another, and from the Lake Superior series just described, but they all include quartzites and limestones or dolomites with some greywacke, slate and, in some cases, iron formation. They can generally be seen to rest uncomformably on the older rocks and their fold structures commonly cut across the regional trend of the Early Pre-Cambrian formations. These points and the wide spacing are the ones which are relevant to this argument. Good descriptions are now available in reports of the Geological Survey of Canada and summaries can be found in publications by H. C. Cooke (1947) and M. E. Wilson (1941, 1939).

GRENVILLE PROVINCE

The south-eastern margin of the Shield, extending inward about 200 miles from its south-eastern edge, differs from those parts of comparable size previously discussed in the complete absence of the typical Early Pre-Cambrian rocks. It differs from the Late Pre-Cambrian series heretofore discussed in being deformed throughout and generally characterized by medium to high grade metamorphic rocks and intrusives. A third feature worthy of note is the widespread occurrence of anorthosite and anorthositic gabbro.

The commonest rock types are granite and gneisses with quartzites, crystalline limestones and amphibolites in places, mainly in the outer part. Many of the gneisses clearly represent original sediments.

In areas studied so far, the obvious meta-sediments are separated from the typical Early Pre-Cambrian rocks to the north-west by a belt of granite and gneiss or by drift-covered areas, so the age relations between these groups cannot be established by the usual methods. At Lake Mistassini a fault can be seen to separate the gneisses from Late Pre-Cambrian sediments and relations indicative of faulting are known to occur at several points to the south-west and north-east (Norman, 1943; Cooke, 1946, 1947; Gill, 1935). Nothing definite is known as to the character or magnitude of the movement along this belt of faulting but individual fault zones described to date are all steep in dip and it appears probable that movements have occurred in a belt some miles in width. In any case a rapid

change from low grade metamorphics to high grade gneisses occurs along this fairly straight zone, extending from Georgian Bay to the Hamilton River and possibly beyond.

A most significant fact is that within this belt the dominant trend is north-eastward, not just near the line separating it from the Superior Province, but right down to the Shield border. The same trend is continued, with a slight swing, in the Frontenac axis and the Adirondacks in New York state. Here is a belt of rocks characterized by strata that, though metamorphosed, are similar to the Late Pre-Cambrian rocks of the rest of the Shield and quite unlike those of the typical Early Pre-Cambrian. They form a deformed belt with a north-easterly trend cutting sharply across the east-west folds of the Superior Province. If, as has been customary, the Grenville is taken to be as old or older than the Keewatin and Timiskaming type rocks east of Val D'Or, Quebec, the truncation of the east-west folds can be accounted for by large movements on the steep faults mentioned but in this case the impress of the east-west folding would surely be found somewhere nearby in the Grenville Province. Now it is true that this area has not been mapped in detail, but enough is known to indicate that any such broad belt of east-west folding does not appear to the east of the fault zone. The predominant trend throughout this wide belt, parallel to the line of truncation, is, however, exactly what one would expect if a geosyncline and, subsequently, a mountain system formed along this zone *after* the folding of the Archean rocks of the Superior Province. The generally high grade of the exposed rocks to-day (which has been a dominant reason up to now for placing them amongst the oldest series) can be accounted for by persistent uplift and deep erosion of the Shield border. The fault zone mentioned has, no doubt, played an important part in this. This uplift has persisted up to very recent times, as has been pointed out by Cooke (1931), and is clearly shown by the high position of the Shield border and the steep gradients in the lower courses of many of the rivers flowing southward and south-eastward into the Gulf of St. Lawrence.

The only other explanation of the broad relations described is to assume that movements on low angle thrust faults carried the Grenville rocks to their present position from a locale tens of miles to the east. In this case the Grenville rocks could belong to the Early Pre-Cambrian, but detailed mapping along the critical boundary zone has so far failed to reveal any evidence of such thrusts.

As previously stated, there is no way at present known of establishing the age relations between the Grenville mountains and the Penokean mountains to the west. They could be of the same age or markedly different in age. Only further detailed mapping or radioactive dating can settle this point. It does, however, seem clear that both belong to the Late Pre-Cambrian.

General Discussion.—The abrupt change at the unconformities separating the Archean and Proterozoic series, from completely deformed rocks with no limestone or quartzite to formations with limestones and quartzites, deformed only along widely-spaced belts, indicates either rapid change in the conditions of sedimentation, deformation and erosion or else a long period of erosion in the area to produce the contrasts under gradual change. Prolonged erosion appears more probable. The term Eparchean Interval may, therefore, have some validity even under the interpretations advocated in this paper. It should be noted, however, that the duration of erosion would be different in different parts of the Shield and the various separate remnants of Late Pre-Cambrian rocks no doubt formed at widely separated periods.

It would appear that the thin crust of early Pre-Cambrian time was warped, loaded, folded and intruded by igneous rocks along numerous belts and over a long period of time. After each episode, the deformed section was relatively stable and subject to erosion. Thus progressively the crust was thickened. Thereafter, downwarpings were less frequent, more widely spaced and on the average wider, because the crust was thicker and stronger. It may be noted that this progression has apparently continued into later geological time. The Paleozoic and later mountain belts are still more widely spaced and wider, on the average. It is suggested, therefore, that these differences are dependent on a progressively thickening crust.

Discussion of reasons for the absence of limestones and quartzites from the Archean would make this paper unduly long, so it will be left for another paper.

PART XIII: OTHER SUBJECTS

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LES FORMATIONS QUATERNAIRES DE LA PLAGE DU DÉBARQUEMENT BRITANNIQUE DE SAINT-CÔME DE FRESNÉ-ASNELLES BELLE PLAGE (CALVADOS)

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France

RÉSUMÉ

Le site du débarquement britannique de Saint-Côme de Fresné est, sur la côte française de la Manche, le plus remarquable jusqu'ici connu pour l'ensemble des formations quaternaires qui s'y trouvent rassemblées.

Découverts en 1931, les dépôts quaternaires de la plage ont été particulièrement bien exposés jusqu'en 1939. Le remblaiement d'une falaise morte par du head et des limons s'est effectué sur des sables marins à *Modiola modiolus* et *Rhynchonella* cf. *psittacea*, recouverts d'une tourbe compacte à *Elephas primigenius* et *Rhinoceros tichorhinus*, elle-même surmontée d'argiles renfermant, avec la même faune de Mammifères, une riche faune d'eau douce.

Des formations de tourbe plus récentes ont donné lieu à des sondages dont l'étude pollinique est en cours.

L'auteur se propose de compléter les premiers résultats publiés en 1932 et en 1935 sur cette station qui se signale, notamment, par l'abondance des fossiles qu'elle a livrés aux différents horizons. L'exposé sera accompagné de projections ainsi que d'une présentation des faunes recueillies.

LE port de débarquement britannique " Winston Beach " créé en Juin, 1944 devant Arromanches s'étend sur un front de quatre kilomètres de la Pointe de Tracy-sur-Mer à l'Ouest au rocher du Calvados à l'Est. Le site de sa moitié Est, devant Saint-Côme de Fresné et Asnelles Belle-Plage est, sur la côte française de la Manche, le plus remarquable jusqu'ici connu pour l'ensemble des formations quaternaires qui s'y trouvent rassemblées. Ces formations se poursuivent de part et d'autre de la ligne de rivage, vers l'Est, jusqu'à Ver-sur-Mer et au-delà faisant pendant à celles qui ont été décrites par J. Prestwich en 1892 déjà entre Brighton et Portsmouth (Prestwich, 1892).

Les dépôts normanniens (Dangeard, 1936) conservés sur la plateforme littorale à hauteur des rochers de Calvados n'ont d'abord été accessibles à l'observation directe, lors de la découverte du gisement en 1931 (Guillaume, 1935), que sur des affleurements discontinus: sables marins à *Modiola modiolus* dans la plage d'Asnelles; argiles et tourbe compacte à *Elephas primigenius*, 1500 métres plus à l'Ouest, dans la plage de Saint-Côme; les relations de ces dernières avec le head et les limons de la terminaison Est de la falaise de Saint Côme étant masquées par le cordon littoral actuel.

L'exploration du gisement, méthodiquement poursuivie au cours des années suivantes, au gré des remaniements de l'estran, n'a tout d'abord apporté que des précisions sur des points de détail (Guillaume, 1935). Mais, à partir de l'été 1935, de violentes tempêtes ont mis à découvert des affleurements étendus de ces dépôts, lesquels se sont trouvés en particulier magnifiquement exposés jusqu'à l'été 1939, sur la plage de Saint-Côme à l'Ouest de la canalisation de la Gronde.

L'étude de ces affleurements, complétée par des sondages à main a pleinement confirmé la succession stratigraphique primitivement admise sur des coupes fragmentaires. En même temps, elle a fourni des données nouvelles sur l'extension du gisement, sa constitution et les faunes des différentes assises.

Ancien rivage et falaise morte.—La trace de la falaise morte est visible dans la falaise vive actuelle entre Arromanches et Saint-Côme à trois cents mêtres environ de sa terminaison Est. Le head s'accole suivant une surface inclinée d'environ 50° sur l'horizontale aux marnes et marno-calcaires bathoniens qui constituent jusqu'à Arromanches et au-delà la falaise ainsi que le substratum des formations récentes de la plage.

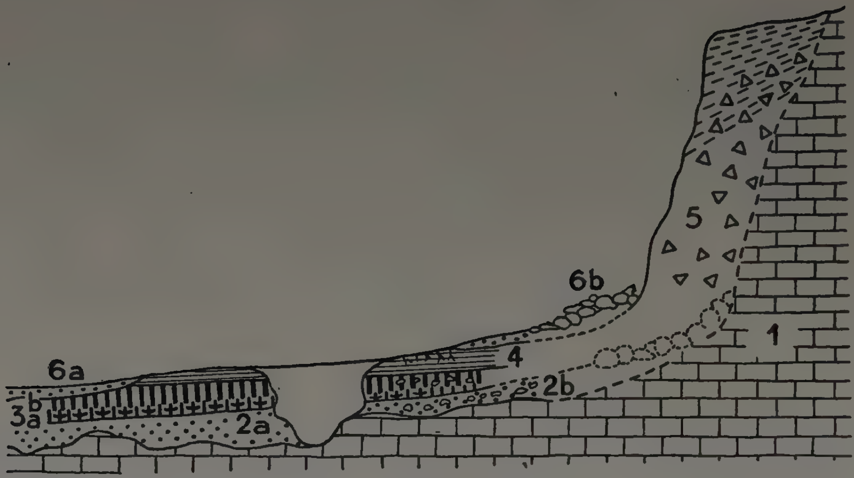

FIG. 1.—*Coupe schématique de la falaise à l'Est de Saint-Côme de Fresné.*

1. Substratum: marnes et calcaires bathoniens.
2. Sables à *Modiola modiolus*, passant latéralement aux cailloutis de l'ancien cordon littoral.
3. Tourbe normanienne compacte: (*a*) Assise inférieure à coquilles marines, (*b*) Assise supérieure à *Elephas primigenius.*
4. Argile verte à *Elephas primigenius*, avec traces de végétation par places.
5. Head.
6. Formations actuelles de la plage: (*a*) Sables, (*b*) Cordon littoral.

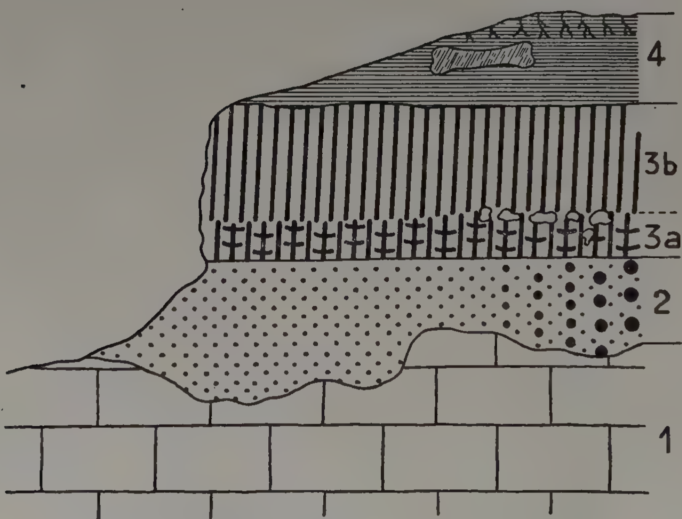

FIG. 2.—*Formations normaniennes de la plage de Saint-Côme de Fresné.*

1. Substratum: marnes et calcaires bathoniens.
2. Sables à *Modiola modiolus*, passant lateralement aux cailloutis de l'ancien cordon littoral.
3. Tourbe normanienne: (*a*) Assise inférieure à coquilles marines, (*b*) Assise supérieure à *Elephas primigenius.*
4. Argile verte à *Elephas primigenius*, avec traces de végétation par places.

La direction de l'ancien rivage est marquée par les lambeaux de l'ancien cordon littoral plaqués sur les marno-calcaires bathoniens de la plage jusqu'à plus d'une centaine de mètres vers l'Ouest de la trace de la falaise morte. Elle était orientée approximativement W.N.W.–E.S.E., faisant un angle d'environ 30° avec le rivage actuel.

Sables normanniens à Modiola modiolus.—Ces sables ont été mis à nu dans de nombreuses mares échelonnées sur une longueur de près de 500 mètres à l'Ouest de la canalisation de la Gronde. En quelques points où leur substratum a été dégagé par les affouillements, ils reposent directement sur les marno-calcaires du Bathonien inférieur.

Ces sables sont en partie fortement argileux, généralement gris; par place, ils sont fortement chargés de glauconie qui leur communique une teinte verte. Localement, par altération, ils sont jaune d'or. Vers l'extrémité Ouest du gisement et en direction de la falaise, ils font place latéralement aux cailloutis, partiellement cimentés en conglomérats du cordon littoral ancien.

A l'Ouest de la Gronde, l'épaisseur de ces sables est généralement inférieure à un mètre. Des sondages ont permis d'établir que ces sables se continuent sans interruption vers l'Est, en augmentant d'épaisseur, jusqu'au delà de l'extrémité Est de la digue d'Asnelles où un sondage en a traversé trois mètres sans atteindre leur base.

Sur la plage d'Asnelles, les affleurements observés en 1931 avaient à peu près complètement disparu en 1932, mais de nouveaux affleurements apparus depuis à deux cents mètres du rivage, à hauteur du milieu de la digue, ont montré, intercalées dans les sables jaune d'or, des plaquettes d'un grès calcaire à surfaces irrégulières, renfermant *Macoma balthica*, *Modiola modiolus*, etc. Des galets provenant de ces bancs ou de bancs analogues se retrouvent beaucoup plus à l'Est, notamment sur la plage de Courseulles.

Ces sables renferment une faune très riche en individus, sinon en espèces, dans laquelle j'ai déterminé:

	1	2	3
Rhynchonella cf. *psittacea* Chemn. ....(A)		ac	
Mytilus edulis L. ....(B)	cc	cc	cc
Modiola modiolus L. ....(B)	ac	ccc	cc
Cardium nodosum Turt. ....(B)		rr	
Astarte montagui = *A. compressa* Montagu............................(A)		r	
Astarte sulcata Da Costa ....(B)		r	
Astarte sulcata Da Costa *Lucina* sp. ....(B)		r	
Mactra elliptica Brown ....(B)		r	
Macoma balthica L. ....(B)	cc	ccc	ccc
Mya truncata L. ....(A)		r	r
Gibbula cineraria L. ....(B)		r	
Littorina littorea L. ....(B)	r		
Littorina obtusata L. ....(B)	c	cc	r
Lacuna vincta Montagu = *divarivata* Fabr. *non* L. ....(A)		rr	
Purpura lapillus L. ....(B)	c	r	
Buccinum undatum L. ....(B)		r(1)	r(2)
Balanus sp.			

1. Saint-Côme, face à la trace de la falaise morte. 2. Saint-Côme, face à la terminaison E. de la falaise. 3. Asnelles, face au Préventorium de filles.
(A) Arctique; (B) Boréale.
(1) Grande et petite taille; (2) Forme à test mince.

Les formes les plus abondamment représentées sont *Macoma balthica* L., *Modiola modiolus* L., *Mytilus edulis* L. Deux espèces au moins, *M. modiolus* et *Rhynchonella psittacea* Chemn. semblent avoir

disparu de la Manche à l'époque actuelle et se retrouvent, la première dans la Mer du Nord, la seconde dans les mers polaires.

La faune de Foraminifères, étudiée en 1935 par V. Pérébaskine a été revue par Y. Le Calvez et P. Marie sur des échantillons plus importants. Ces auteurs ont reconnu les formes suivantes:

	1	2
Lagena laevis Montagu	r	
— *globosa* Montagu	r	
— *acuticosta* Reuss	r	r
— *hexagona* Williamson	r	
Cristellaria gibba d'Orb.	r	r
Bulimina marginata d'Orb.	ac	
Bolivina punctata d'Orb.	ac	r
Angulogerina angulosa Will.	r	r
Quinqueloculina seminulum	r	r
Elphidium crispum	r	r
— cf. *listeri* d'Orb.	r	r
— *macellum* Ficht. et M.	r	r
— *incertum* Will.		cc
— *excavatum* Terq.		ccc
— cf. *stella-borealis* Ehren.		ccc
Elphidium cf. *lidoensis* Cushm.		cc
— *selseyensis* H. All.-Earl.		c
Nonion laeve d'Orb.		c
— cf. *roemeri* Reuss	r	
Sigmomorphina williamsoni Terq.	r	
Patellina corrugata Will.	r	
Rotalia beccarii L. var. *pliocenica* t' Dam. et Reinh.	r	r
Discorbis sp.	r	r
— *mamilla* Will.	ar	r
— *orbicularis* d'Orb.	r	ac
Cibicides lobatulus W. et J.	cc	cc
Cibicidella variabilis d'Orb.		r

1. Saint-Côme, face à la terminaison E. de la falaise. 2. Asnelles, face au Préventorium de Filles.

Y. Le Calvez et P. Marie notent que les formes d'Asnelles ont des dimensions normales tandis que celles en provenance de Saint-Côme sont toutes de petite taille. Il s'agit exclusivement de formes littorales, déjà connues pour la plupart dans le Pliocène moyen (Scaldisien) néerlandais.

En outre, il a été retrouvé les formes suivantes, remaniées du Jurassique moyen:

	1	2
Verneuilina cf. *mauritii* Terq.	r	
Paalzowella cf. *conica* Schl.	r	r
Conicospirillina trochoides Berth.	r	r
— sp.	r	
Spirillina sp.	r	r

La faune d'Ostracodes de ces sables est également très variée. Etudiée avant 1939 par M. Triebel qui y avait reconnu onze espèces de caractère arcto-boréal, elle a été très soigneusement revue sur des

matériaux plus importants par Y. Lucquiaud qui a déterminé une vingtaine de formes dont la liste sera donnée plus loin et paraissant correspondre à une faune littorale de mer froide.

Tourbe compacte à Elephas primigenius.—Dans la région à l'Ouest de la Gronde, les sables et conglomérats à *Modiola modiolus* sont recouverts par une couche de tourbe compacte à éléments relativement fins, dont l'épaisseur totale, atteignant 50 à 60 cm. vers la terminaison Ouest du gisement, se réduit vers l'Est à 10–20 cm. et finit même par manquer localement peu à l'Ouest de la canalisation de la Gronde. A l'Est de la Gronde, elle fait généralement défaut. Cependant, elle a été rencontrée, sous une épaisseur de 10 cm. environ dans un sondage à peu de distance de l'extrémité Ouest de la digue d'Asnelles.

À la partie inférieure de cette tourbe, abondent des coquilles marines, Moules et Modioles, en exemplaires de grande taille, à valves étalées, très friables, formant un lit de grande continuité. Vers l'extrémité Ouest du gisement, il s'y intercale même des lentilles de galets et de graviers atteignant 10 ou 20 cm. d'épaisseur avec une profusion de débris de mêmes coquilles.

Dans la partie supérieure, déposée semble-t-il en parfaite continuité, les fossiles marins font défaut et l'on rencontre par contre en plus ou moins grande abondance suivant les points des coquilles de Gastropodes et Lamellibranches fluviatiles qui se retrouvent dans les argiles sous-jacentes. C'est à ce niveau qu'on été rencontrés de nombreux restes de Mammifères:

Elephas primigenius	(dont un squelette entier)
Rhinoceros tichorhinus	(dont un crâne entier)
Cervus sp.	
Equus caballus, de grande taille	
Bison priseus	
Bos sp.	
Canis lupus.	

Jusqu'ici, cette tourbe n'a pas livré de silex taillés.

Argiles vertes à Elephas primigenius.—A sa partie supérieure, sur 10 à 20 cm., la tourbe se charge progressivement d'argile et passe finalement à une argile verte, jaunâtre par altération. Ces argiles sont plus ou moins fortement chargées de calcaire et renferment par place de véritables agglomérations de glauconie. Les Gastropodes et Lamellibranches fluviales y sont extrêmement abondants, soit en débris, soit en individus entiers. Je donne une liste de cette faune dont les déterminations ont été revues par Jules Favre du Musée d'Histoire Naturelle de Genève:

Vallonia pulchella Müller	rr
Helix hispida L.	rr
Pupilla alpicola Charp.	rr
Succinea P *feifferi* Rossm.	cc
Limnaea peregra Müller	cc
— *palustris* Müller	cc
Planorbis planorbis L.	ccc
— *rotundatus* Poiret	c
— *crista* L.	c
Pisidium vincentianum B.B.W.	c
— *obtusale* C. Pf. var *lapponicum* Cless.	c
— *milium* Held.	cc
— *casertanum* Poli.	rr
Cyamium minutum Fabr.	rr
Limacelles variées	cc
Corpuscules d'*Arion*?	cc

Parmi ces espèces, selon J. Favre, trois présenteraient un intérêt particulier comme ayant disparu de l'Europe occidentale, connues seulement de gisements quaternaires, et se seraient retirés vers l'Europe centrale ou orientale (*Pupilla alpicola* Charp.), l'une vers le Nord, en Laponie (*Pisidium obtusale*, C. Pf. var *lapponica* Clessin), l'autre vers l'Est (*Pisidium vincentianum* B.B. Woodw.).

Outre cette taune malacologique, les argiles renferment en grande abondance des oogones de Characées et elles ont livré une faunule d'Ostracodes d'eau douce étudiée par Melle Y. Lucquiaux qui donne dans le tableau ci-dessous la répartition des différentes espèces reconnues dans les diverses formations:

(1) Sables marins à *Modiola modiolus.*
(2) Tourbe normannienne inférieure (avec coquilles marines).
(3) Tourbe normannienne supérieure à *El. primigenius.*
(4) Argiles vertes à *El. primigenius.*

	1	2	3	4
Cythere villosa (Sars)	ccc	cc	—	—
— *pulchella* Brady	r	r	—	—
— *finmarchica* (Sars)	cc	cc	—	—
— *tuberculata* ,,	rr	r	—	—
— *angulata* (Sars)	r	cc	—	—
— *viridis* Müller	r	r	—	—
— *lutea* Müller	ccc	ccc	rr	—
— *oblonga* Brady	rr	r	rr	—
— *convexa* Baird	rr	r	rr	—
— *pellucida* Baird	—	rr	rr	—
— *cuneiformis* Brady	—	rr	—	—
Cytherura undata Sars	rr	rr	—	—
— *clathrata* Sars	r	rr	—	—
— *nigrescens* (Baird)	rr	rr	—	—
— *similis* Sars	rr	—	—	—
— *sarsidi* Brady	rr	—	—	—
Eucythere declivis (Norman)	rr	r	—	—
Cytheropteron nodosum Brady	rr	rr	—	—
— *latissimum* (Norman)	r	c	rr	—
Loxoconcha tamarindus (Jones)	rr	rr	—	—
— *impressa* (Baird)	—	rr	rr	—
Cytheridea elongata Brady	rr	rr	—	—
Bairdia sp.	rr	rr	rr	—
Candona candida (Müller) *tumida* Brady et Robertson	—	rr	rr	ccc
Candona neglecta Sars	—	—	—	r
— *reptans* Baird	—	—	—	rr
Cypris ventricosa? Brady—Robertson	—	rr	—	—
— aff. *ornata* Heller	—	—	—	r
— *serrata* (Norman)	—	—	—	rr
Ilyocypris gibba (Ramdohr)	—	—	—	ccc
— *bradyi* Sars	—	rr	rr	ccc
Potamocypris smaragdina (Vevra)	—	—	—	c

La faune de Mammifères ne semble pas présenter de différences importantes avec celle de la tourbe. Outre des Bovidés et des Chevaux de grande taille, j'ai pu y recueillir, sur une superficie restreinte des restes appartenant à six individus différents d'*Elephas primigenius* et à cinq de *Rhinoceros tichorhinus.* A noter également un fragment de mandibule d'un Cerf de grande taille (*Cervus* ou *Megaceros*?) ainsi qu'une molaire (en mauvais état de conservation) d'*Elephas Trogontherii* (det. G. Stehlin).

Les restes d'industrie humaine sont très rares dans les argiles. Jusqu'ici, trois silex taillés seulement y ont été recueillis: une lame, ainsi que deux pointes avec traces d'utilisation, d'une industrie du Paléolithique moyen selon Paul Wernert.

A l'Ouest de la Gronde, les argiles ont leur affleurement limité en direction de la falaise par les sables et les galets du cordon littoral masquant les relations avec les limons de solifluction ayant remblayé la falaise morte. Un forage effectué à une quinzaine de mètres en arrière du rivage, près la terminaison Est de la falaise de Saint-Côme, a permis de relever la coupe suivante:

0 – 0m,85	terre finement sableuse, de teinte grise, riche en matières humiques
0,85 – 1,80	limon jaune clair
1,80 – 2,20	limon jaune d'or, avec graviers de 2 à 2m,20
2,20 – 2,80	sable argileux fin, jaune d'or
2,80 – 2,95	sable argileux blanc
2,95 – 3,00	sable argileux gris mélangé de tourbe
3,00 – 3,40	tourbe fine noire
3,40 – 3,60	sable jaune d'or et graviers

Ce sondage dans lequel la tourbe traversée entre 2m,95 et 3m,40 correspond à la tourbe monastirienne démontre que cette tourbe passe indiscutablement sous les limons et qu'elle repose elle-même sur des sables qui ne peuvent guère être interprétés que comme d'âge normannien.

A l'Est de la Gronde, les argiles à faune froide semblent avoir disparu. Il semble bien cependant qu'elles aient été autrefois déposées ainsi que tendrait à le montrer la présence de Planorbes dans un lit argileux surmontant les sables jaune d'or de la plage d'Asnelles.

Head et limons.—Ces formations qui ont remblayé la falaise morte et recouvert les dépôts qui précèdent atteignent à leur maximum de hauteur une puissance d'une quinzaine de mètres. Les affleurements de head sont en grande partie masqués dans la falaise actuelle par des éboulis. La partie terminale, vers l'Est, où les limons montrent une meilleure stabilité, a été entaillée pour l'installation d'un pont de débarquement. A hauteur de ce point, j'ai recueilli dans ces limons quelques fragments de gros Mammifères et notamment, dans la partie moyenne, un métapode de *Rhinoceros tichorhinus* (det. G. Stehlin).

Tourbe flandrienne.—Elle se rencontre en lambeaux discontinus d'une part entre la Gronde et l'extrémité Ouest de la digue d'Asnelles et d'autre part à l'Est d'Asnelles. Sans revenir sur les conditions de gisement, je me bornerai à donner ici les résultats de l'étude pollinique qui en a été fait par Madame Van Campo.*

Tourbes d'Asnelles fournies par Monsieur Guillaume.—" Tous les sédiments analysés se sont révélés très pauvres en pollen.

Les sondages S_2, S_1 pràtiqués en T_1 ont donné les résultats suivants:

0m,25–0m,75 pollens de: Ifs, Chênes, Ormes, Saules, quelques Noisetiers.

0m,75–2m,00 Couches très pauvres en débris végétaux.

2m,00–3m,50 Pollens de Pin type silvestris.

Deux faits doivent être notés:

(*a*) présence à la base des couches de pollens de Pin.

(*b*) absence dans les couches superficielles de pollens de Hêtre et de Sapin (les forêts de Hêtres et de Sapins ont eu une grande extension en Normandie après la période atlantique).

L'ensemble des couches étudiées semble donc appartenir à la période s'étendant du *Boréal sec* au *Subboréal chaud sec* soit environ de 7 à 8000 ans à 1500 ans. Les couches tourbeuses ont été par la suite recouvertes de sédiments.

Les pollens de Pin apparaissent un peu plus tôt dans les sondages faits en T_2 qu'en T_1, les couches descendent donc en pente douce vers la mer.

Note.—La présence de pollen de Pin maritime dans le sondage S_1 de T_1' au niveau 0m, 25 n'a pas de signification climatique, mais indique au contraire que des pollens actuels ont été transportés à

* Echantillons provenant de divers sondages exécutés à l'Est d'Asnelles.

FIG. 3.—*Affleurements des dépots quaternaires sur la plage du débarquement britannique (6 juin 1944) à St. Côme-de-Fresne—Asnelles—Belle-Plage.*

une profondeur notable. Toutefois je ne pense pas que d'autres éléments soient venus fausser le résultat des analyses."

Analyse effectuée par Madame Van Campo le 27 Juin 1948. (Méthode Erdtman).

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TOPOGRAPHY AS A FACTOR IN STRUCTURAL GEOLOGY

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ABSTRACT

The effect of topography in producing and modifying small structures found on the surface of the earth has become widely recognized. The question as to whether or how much topography in ancient times may have been a factor in the initiation and growth of larger structures is much more controversial because it is difficult to demonstrate.

In the sense that a diamond scratch on the surface of a sheet of glass exercises far more influence upon the behaviour of that sheet when stressed than its casual appearance would warrant, so the existing pattern upon the earth's surface at a time just before the on-set of mountain building, is regarded as an important influence in determining where and how folding or faulting may have developed in the packet of strata below, when this was subjected to pressure. A few examples which seem to bear out this hypothesis are described from a part of the Zagros Mountains where two pulses of crustal shortening occurred, separated by a long time interval.

LANDSLIDES (Sharpe, 1938) have long been familiar to man as an effect of the force of gravity. Surface creep (Geikie, 1920, p. 131) is also well known. Much pit evidence from Trinidad, B.W.I., revealed widespread disturbances as a result of slow slipping below slopes of moderate inclination. " Rivers of ice " (Tyndall & Huxley, 1857; Tyndall, 1860) imply plastic flow of a solid under very small forces. Salt and gypsum take the place of ice in Persian " salt glaciers " (Harrison, 1930; Lees, 1927). Recrystallization takes place (Harker, 1933, pp. 30-33) to make such plastic flow possible.

The disturbance of natural slopes sometimes leads to slipping above, and to upheaval below as in the Culebra Cut of the Panama Canal. Hard beds resting upon clay or shale tilt and rotate as the soft rock below is squeezed out (Hollingworth, Taylor and Kellaway, 1944; Ward, 1945; Steers, 1946). Comparable structures are shown in the Oolites of the Cotswold Hills (Geological Survey map, Sheet 235). On a larger scale, nummulitic limestone resting upon shales in Luristan (33° 35′ N.; 47° 15′ E.) (Harrison, 1946, p. 60) exhibits disturbances of like kind. Drilling often proves that shale is squeezed out towards an outcrop between beds of sandstone.

Structures formed by slumping in water-logged sediments occur in many lands in beds of many ages. One beautiful example is exposed in a sea cliff near Erin in Southern Trinidad, B.W.I. The processes involved have been discussed by Hills (1940, pp. 14–17). As in the case of a landslip the initial slope required to start a slide may be greater than that upon which it keeps moving (Jones, 1940, p. 355). Flow-folding affects marble (Bain, 1931) and the Eocene Flysch in the Indus Valley (de Terra, 1913). Packets of limestone have collapsed under gravity in Persia (Harrison & Falcon, 1934) and in the Jura Mountains (Castany, 1947).

Blocks may also slip down dip along bedding planes as happens in Coastal Peru (Baldry, 1938; Brown, 1938). A road cutting on Morro Solar near Lima shows a vertical dyke cutting gently dipping sediments (Fig. 1). The dyke has been sliced off at two levels and each time the higher block moved seawards, the fault plane being a bedding plane. Terraces are developed along this coast to heights greater than 1000 feet above sea level and are mainly younger than the faulting. Therefore the slipping occurred under considerable cover.

The structures so far listed have occurred because some slope was too steep for equilibrium and either the top layers slipped off or moved, or the underground was squeezed out and moved laterally. Time is undoubtedly an important factor in the production of all such structures (Gignoux & Moret, 1938; Cloos, 1931, p. 242). Next to be considered is the case of the structure modified or controlled by a surface feature already modelled. The case of ice is commonplace, since a glacier keeps to its

valley and is moulded by it. Rock debris as it falls off a mountain may be subjected to similar control (Harrison, 1936a, Pl. opp. p. 20).

An object lesson on a small scale was provided by an eruption in 1927 of the Devil's Woodyard mud volcano in Trinidad, B.W.I. It produced a mud cake about 6 ft. thick and 300 ft. in diameter overnight. It had steep sides and lay upon a clay floor which had been maturely eroded by the weathering of a sheet of mud erupted in the same manner some years before. The new load laid upon this floor by the eruption produced in it little folds concentric with the upstanding clay flood. Most of these folds were symmetrical but at one point where they straddled a " river " flowing away radially the folds became asymmetrical at first and near the valley bottom the fold was broken and formed a low angle thrust. At the time of these events the " river " was quite dry and its valley about 12 inches deep.

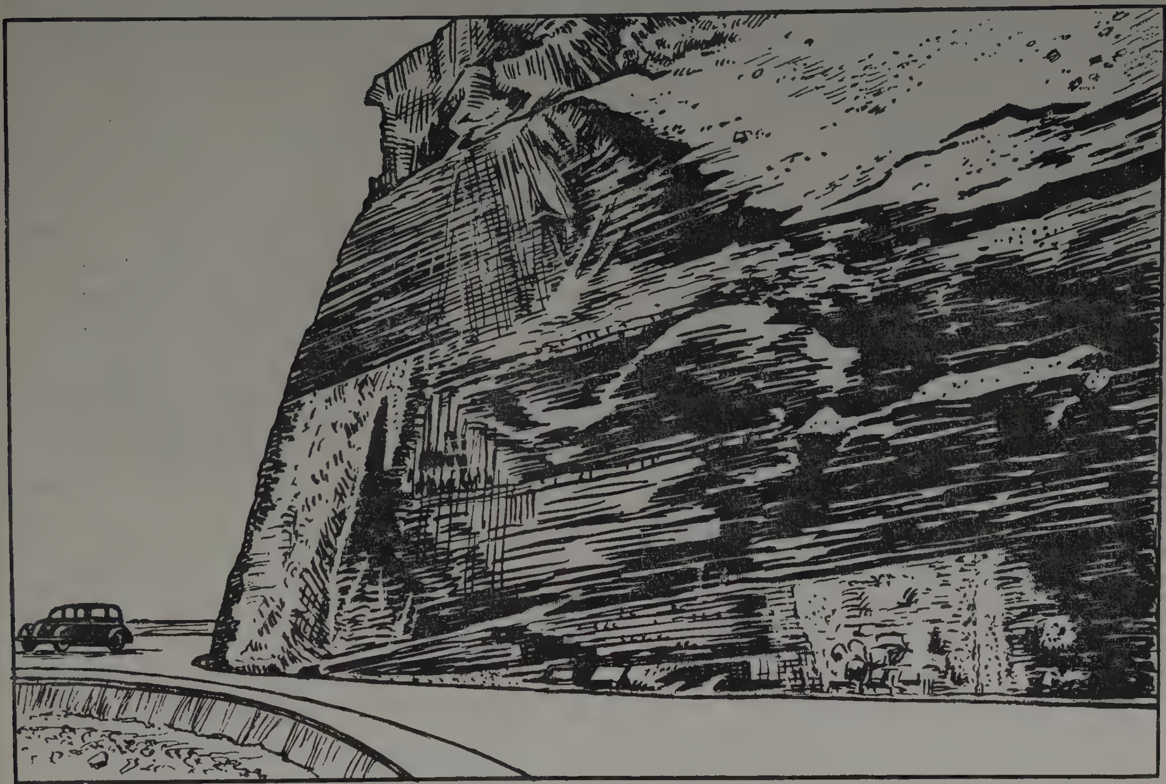

FIG. 1.—*Road section at Morro Solar, near Lima, Peru. A dyke cutting the Cretaceous shales and sandstones is cut by a fault following a bedding plane and moved about 10 yards to the west.*

On a much larger scale the response of structure to topography is demonstrated in the Zagros mountains near Chulbar (32° 21′ N.; 49° 25′ E.). There, the central of three anticlinal units plunges to the south-east, leaving the two outer folds with a broad syncline between them. The south-western fold goes straight on and commences to lose height towards its distant plunge, but the fold on the north-east, which has been regular for many miles where it has had the support of its neighbour on the south-west, becomes irregular. Its axis twists forward; the fold expands from 3 to 5 miles wide; and the symmetry of its cross section is lost for a few miles by the steepening and over-turning of its south-western limb. The mountains of this group of ranges have been erected by post-Cretaceous movements which rose to a climax in the Mio-Pliocene, but the process of arching seems to have gone on in stages with minor episodes of erosion intervening.

In the small scale geological map of Scotland which shows the outcrops of the Assynt District made famous by the work of Lapworth, Peach and Horne, a remarkable feature is the width of the Cambrian outcrop depicted between Lochs Assynt and Borolan. This seems to be due to the Loch Borolan syenite complex either holding up the westward-thrust sheet of Moine schists, or else arching it so that erosion has attacked it more vigorously here than elsewhere along its trace.

The Western Alps afford another instance of a region where mountains of an earlier folding had a vast effect upon the arrangement of later folds. The Hercynian massifs like Mont Blanc and the Aar stand in line with a saddle between them. The calcareous nappes of the Helvetian group were able to move to the north across this low col much more easily than over the high massifs. One may refer to the well-known diagram by Arbenz (Collet, 1927 fig. 14, p. 61) and to the more detailed sections of Albert Heim (Heim, 1921, Tafel xviii, p. 384). Kober, in Austria, has also stressed this coercion, the constraint of the northward-moving nappes into sundry saddles. The same theme has recently been recalled in connection with the behaviour of slices of limestone sheets in the Alps of Southern France, between Pelvoux and Mercantour (Chardonnet, 1944).

These few examples show that the arrangement of folds and fault sheets may be strongly affected by irregularities of an ancient landscape. Some descriptions follow which may demonstrate that the earlier topography affects the outline of certain folds themselves. That such changes of form do happen as a result of more than one phase of compression is a conclusion reached by a few geologists, but the ravages of erosion make proof difficult and evidence is often so obscured that the validity of the deductions made may be disputed. Many experiments have been devised throughout the last century to demonstrate the effect of compression upon media chosen, with varying success, to simulate packets of strata. Compression has been stopped at several stages, for recording, then renewed and intensified. The folded masses so produced are thus examples, not of a single shortening, but of many. In most of these experiments interludes of erosion have not been introduced, plenty of cover usually being maintained. The conditions of the experiments have always required that sliding could take place over a rigid basement. In nature many of the mountain building paroxysms have recurred after some or perhaps much erosion has taken place and the lubricant at the base is only sometimes present. The comparative rarity of mountains which conform to the simple plan presented by the experiments may be due to the scarcity of rock packets which are uniform over large areas, but when these approach the ideal then the structures tend to do so also. The Jura Mountains of France and Switzerland provide a classical case in Europe, the Appalachian Mountains an equivalent in North America, and the Zagros Mountains one in Asia. However ideal may be the original uniformity of the rock column, once this is folded and some erosion has occurred this uniformity is lost. The upper surface is roughened, the bottom of the sheet is corrugated, and its properties of constant thickness and strength destroyed.

As if the many models of mountains produced by compression experiments did not lay enough emphasis upon the spasmodic growth of folds, the serial profiles across the Alps by Argand provide a caricature of this process inferred for the events as they are understood in Switzerland (Collet, 1927, Pl. I). More recently, such jerky growth of the Alpine structures near Grenoble has been portrayed in a series of diagrams, taken up to the Eocene, when the mountain folds were still rather open (Gignoux and Moret, 1938).

A brilliant study of the growth of mountain structures which still retain reasonable forms and some simplicity was published in 1892 (Bailey Willis, 1892). This is all the more remarkable because a complicated late physiographic history makes an interpretation of some of the stages difficult in the well-wooded Appalachian Mountains, but by keen observation and clear reasoning it was deduced that in certain cases some erosion of folds had occurred before thrusting during subsequent compression (Bailey and Robin Willis, 1934, pp. 175–179). The gist of the enquiry was summed up by W. M. Davis who said that " the over-thrusts were produced at a later date than that of the general folding of the region and that these two disturbances were separated by a period of time long enough for the accomplishment of a considerable amount of erosion." (Hayes, 1891).

The Zagros Ranges in Persia provide unparallelled opportunities for the study of the development of structures, for not only were the steps in the mountain building made at several times but the movements were not so severe as in the Swiss Alps. Furthermore, the climatic conditions have kept the outcrops clean and neither ice nor soil nor forest obscures the geology. In a central part of these chains between the head of the Persian Gulf and Isfahan the mountains consist of three main tectonic components (Harrison, 1936b). The first, on the north-eastern side, was folded probably late in Jurassic time. A spell of erosion then etched out the folds and filled their fore-deep with flysch in Lower Cretaceous times. They became involved in vigorous folding during the Upper Cretaceous and suffered strong distortion and rupture. At the same time a second group of lusty domes was erected, preserved in the massive Cretaceous limestones and older beds that lay to the south-west of the first ranges. A new fore-deep yawned on the south-west and in it collected thick masses of flysch of late Cretaceous and early Eocene age, derived from the debris worn from this second set of emergent folds. The flysch made good the irregularities of the floor of the fore-deep and thus levelled the sea floor, affording an appropriate site for a mighty deposit of Miocene limestone 900 miles long, 100 miles across and about 1,000 feet thick. The third group of convulsions, ending in Pliocene times, crumpled this immense sheet into a pattern of rather regular folds of Jura type. The slightly curving trend of the ranges is crossed here and there by transverse faults just as in Europe. The belt of country lying to the north-east which, at the beginning of the Palaeocene had upstanding folds of Cretaceous Limestone, was treated rather roughly at this time. Some of the folds which suffered were nearly entire uneroded domes. In others the centres had been eaten out by weathering. Some of these folds were slightly, others drastically, affected. It is from examples in this twice compressed part of the ranges that illustrations are drawn in support of the contention that modification of structural growth by topography can be found in process of evolution.

The present landforms in Luristan or Kuhgalu may be taken as the kind that existed sometime between Maestrichtian and Lower Miocene times. Long regular folds controlled by thick limestones which lay in part intact, in part worn away into opposing escarpments, were breached, perhaps in the middle, by a transverse stream and connected together by amphitheatrical cliffs at each end. Only the simple part of this pattern would be developed where uplift above sea level was slight, and part of the folded surface would lie below sea level, where the synclines would not be cleared out. Kainozoic rocks were laid down upon some of the corrugations, filling some of the hollows completely, others only partly. As the first example Kuh-i-Shahnishin (33° 44′ N.; 48° 40′ E.) standing south of Burujird will serve. It is a long fairly regular hump of Cretaceous limestone, apparently not much different from the kind of fold that stood there in Upper Cretaceous times. It has a partial cover of Kainozoic rocks preserved upon its south-western flank, where dips indicate that the Pliocene folding affected all the rocks, tilting them to about 20° (Fig. 2). Secondly at Ganduman (31° 50′ N.; 51° 15′ E.) a mountain is formed of Cretaceous limestone and would look quite a normal dome if seen from a little distance through a hazy atmosphere, but in the remorselessly clear air and bright light of high Persia it looks ragged and worm-eaten. The extremely smooth contours of the simple domes are missing and the regular dips have been disturbed. Instead of the broad ample back of a circus horse it shows an irregular pinched sharp edge like a scrag at the knackery. The bedded limestone is replaced by a rock often veined with calcite and riddled with joints. On account of its intensely jointed nature dips are hard to find and can indeed be detected in only a few places. Such features are interpreted by supposing that a dome due to the Upper Cretaceous orogeny was etched out after a time and distorted during the Mio-Pliocene movements. Thirdly, a group of rather mis-shapen domes like the one just described form the hills near Kuh-yi-Akhireh (31° 41′ N.; 51° 20′ E.). They are crowded together by the second phase of the movement but are arranged according to a plan recalling domes en échelon, characteristic of the folds preserved in the Miocene limestone. The lower slopes and synclines have suffered most severely through jointing and veining, and it is seldom that dips can be discerned except upon high shoulders. Fourthly, some domes are wrecked and wrought into a massif upon which many little spiky prominences have developed, another aspect of the deformation by crushing.

Kuh-i-Chia Wizan (34° 9′ N.; 47° 43′ E), Fig. 3, shows clearly the features that result in such a case although examples are rare. Fifthly, the magnificent scenery of the limestone massif of Kuh-i-Parau (34° 23′ N.; 47° 20′ E.) (Harrison, 1946, Pl. II) near Kermanshah is derived from a group of clean-swept limestone waves, originally with smooth outlines. Now the anticlines have been crowded together, the empty troughs closed tight and tilted towards the west during the second surge of shortening. Substantial thrust faulting has occurred to assist in the accommodation of the rock waves, the one against the other. The structure is typical of what has been termed the " Crush Zone " in the Zagros Mountains. Sixthly, the section across the mountain Dul Gharib (31° 29′ N.; 51° 45′ E.) in this same district exposes a series of slices of Cretaceous limestone with some crushed igneous rock

FIG. 2.—*Kuh-i-Shahnischin seen from the north-west shows an anticline controlled by Middle Cretaceous Limestone covered in part by Kainozoic beds which have been folded later to dip at about* 30°. *As a result the twice folded Cretaceous Limestone is not ragged.*

like basalt and some sage grey silts like the beds of the Upper Cretaceous and Lower Eocene flysch of the region. This section by itself would mean little, but compared with others exposed in the neighbouring mountains it seems to be an advanced case of the shutting-up of Cretaceous folds, with some of the later deposits retained to mark more clearly the position of the synclines. Both at Harsin (34° 17′ N.; 47° 35′ E.) and Kaka Reza (33° 42′ N.; 48° 14′ E.) the presence of Miocene limestones within the synclines allows a measure of the amount of folding that has taken place at the second stage, and in both cases it is of the order of 30°. A little further back, that is to the north-east, structures are found with only the south-western filling of the synclines left and that preserved beneath a thrust block of limestone. The strip of country in which many examples of all these stages of disturbance may be seen extends for 500 miles in an east-south-easterly direction from Kermanshah and is up to some 20 miles across.

In the light of this Persian evidence, particular significance is attached to the small lenses of flysch shown in many of the profiles drawn across parts of the French and Swiss Alps, especially where they lie beneath slices of older limestones, sometimes inverted, sometimes the right way up. For example, the section across the Col Tronchet in the upper part of the Durance basin in France shows the kind of thing admirably and so does the diagrammatic synopsis of the tectonics of the Mountains of Escreins. (Blanchet, 1934, Fig. 6, p. 129 and Pl. III, Fig. 2). Flysch is *par excellence* the formation of a fore-deep. It fills the troughs and makes good the corrugations which characterize the depression in front of a new-born range. Flysch is a rather fragile deposit, being often imperfectly cemented, easily weathered away or rubbed off in mountain-forming movements. Thin sheets of flysch are unlikely to be preserved except in sheltered places such as the central parts of synclines and the preservation

FIG. 3.—*Kuh-i-Chia Wizan seen from the west. This was a smooth dome of limestone at the end of the Cretaceous but one which was ruined by the Pliocene orogeny and ornamented by many little limestone pyramids.*

of fragments of flysch amongst slices of older limestones or other rocks may point to the site of an evacuated syncline at an earlier stage, perhaps one it would be almost impossible to locate in any other manner. It is suggested that the presence of small wedges of flysch may be a clue to the analysis of tightly folded structures of Alpine type, and may reveal the situation of earlier synclines which had been partly cleaned out and formed into valleys.

To pass on from the realm of observation and observation with inference to that of sheer speculation, a topic which invites discussion, is whether or not the shape of the edges of the " Shields " expressed topographically has had much effect on the pattern of mountain chains. Where the map or plan shows projections and embayments, the mountain ranges close to them probably respond and the syntaxes and deflections recognized since Suess's first synthesis of the geology of the world are the

results. One spectacular deflection of the Alpine orogeny is that of the north-western Himalaya (Wadia, 1931). He attributes the bunching and bending of the chains to this very cause, a wrapping of the mobile belt round a northern cape on Gondwana Land. Almost as striking is the behaviour of both folds and facies in the corner of South Persia a little north of Minab (27° 15′ N.; 57° 5′ E.) near the Straits of Hormuz (Harrison, 1943). A sharp deflection of the late Kainozoic folds occurs and strong thrusting from north to south affects rocks of earlier ages, whose strike does not bend appreciably. All the pre-Miocene rocks exhibit a great change of facies along a north-south line near Minab, long the site of a ridge. It is tempting to regard this as connected with the promontory of Oman situated about 100 miles to the south. There, an edge of old Arabia was up-standing as a foreland during movements of Upper Cretaceous times (Lees, 1929). Here, in Baluchistan, it stood up in Pliocene times and acted as a cape against which the land waves surged. Where the Tigris enters northern Iraq from Turkey the chains change their trend, swinging through nearly 90°. There is some evidence that the basement is not deeply buried now and that another prong from the Arabian massif projected northward when folding was progressing.

Finally it is possible that the attitude of the edge of a shield may influence the nature of the folds near it as a coast line affects the sea waves which break upon it. The outer ranges of the Alpine chain display very different characters from point to point and these cannot be explained by variations in the kind of rocks forming them. Thus a gently sloping margin may accommodate folds dwindling rather regularly towards it as in the Jura and the Zagros. On the other hand a bold unbevelled edge may be expected to have folds of a more complicated pattern produced near to it, as for instance in the Carpathians (Nowak, 1929).

To sum up, given enough time, topography influences strata in the formation of relatively minor structures in response to the force of gravity. Topography also affects the structures caused by compression. Empty synclines are closed, elevated domes ruined and trend-lines bent. Topography at the edge of a shield may modify the shape of rising folds.

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TECTONIC PROBLEMS OF THE ANDES (OBSERVATIONS 1939-47)

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ABSTRACT

After having studied the tectonics of the great thrust systems of the Alps, the Carpathians and the Himalayas, the writer was anxious to make comparative investigations in the Andes, especially in regions where such thrusting was described, in Argentine (by Keidel) and Peru (by Newell). The conclusion was that there are folded unconformities but nothing similar to alpine thrusting. Local oblique thrust faults excepted, the structure of the Andes is intense autochthonous folding due to lateral compression, combined with a great amount of synorogenic and postorogenic intrusion and extrusion.

As already shown by Steinmann for Peru, the new studies of the writer have revealed several different tectonic phases since the beginning of geological history. In the intermediate periods great vertical movements occurred. Uplifts are proved by peneplained older folds, while geosynclinal subsidence is shown by enormous thicknesses of certain formations: Devonian, Argentine-Bolivia-Peru, 5–10 km.; Cretaceous of North Peru, more than 5 km.; Tertiary Redbeds on the Amazonas side of the Peruvian Cordilleras, 6–8 km. Actually, the Andes of Peru seem to be still rising, as shown by young terraces (Altiplano Uplift, 4,000 m.) and earthquakes, while the eastern border of the Andes, with its flooded plains, is apparently still subsiding. The same is supposed for the troughs of the Pacific, along the coast, with depths of 6–7 km. These two sinking zones seem to balance the Andean uplift.

Some characteristic sections worked out by the writer in the Andes of Argentine and Peru are illustrated and explained.

INTRODUCTION

THE following observations were made in the years 1939–40 and 1943–47 during extensive travelling and systematic tectonic work in the Andes of Patagonia, Northern Argentine and Peru. A number of small papers have been published in Spanish by the Dirección de Minas, Buenos Aires, the University and Museum of La Plata, the Dirección de Minas y Petróleo and the Instituto Geológico del Perú in Lima. Other papers are still awaiting publication while the most complete manuscript on the tectonics of the Precordillera of San Juan has disappeared in Argentine.

In this paper, besides a brief general review, only three of the most interesting sections are described, with the aid of corresponding figures.

When coming to South America in 1939, after having devoted a great part of my life to the overthrust regions of the Alps, the Carpathians and the Himalayas, I was anxious to make comparative observations in the Andes, especially in regions where thrusting might have occurred or had been described, as for instance, by Keidel in Argentine and Newell in Peru. My conclusion was that in both cases autochthonous unconformities have been confused with overthrusts, and that nothing similar to the so-called nappes* of the Alps exists.

However, in addition to the occurrence of asymmetric anticlines, the Andes present numerous oblique thrust-faults and extraordinary local complications unlike anything that I have found so far in other continents, the explanation of which still remains partly problematic. Let us take a look at some examples of this kind.

PRECORDILLERA OF SAN JUAN, ARGENTINE

This Precordillera, situated on the east side of the Andes between latitudes 30° and 33° S., is distinctly different in shape, stratigraphy and tectonics from the High Cordillera. Nicely separated

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* This inadequate expression should be suppressed from the English literature. It was originally used in French for any kind of a sheet or level, as, for instance, for groundwater level (nappe d'eau). The proper terms would be:—in French: *nappe de chevauchement*, in German: *Schubdecke*, in English: thrust-sheet, thrust-fold or thrust-mass.

from the latter by the wide synclinal Tertiary valley of Rio de los Patos and its northern and southern continuations, it has a width of 100 kilometres and is cut across by the Rio San Juan which gathers its waters from the synclinal valley. The section along this river, partly displayed in tremendous gorges, has been described in detail in the lost manuscript. It is chiefly made up of intensely folded Palaeozoic sediments, the section ranging from Cambrian to Tertiary, the Jurassic and Cretaceous being undeveloped. These latter, on the other hand, are well exposed in the High Cordillera where they are richly fossiliferous, with abundant ammonites of Liassic and Dogger age.

The Cambro-Ordovician, in the Precordillera, is represented by a marine limestone 1000 metres thick, the Gotlandian in the facies of variegated slates and quartzites, and the Devonian in dark greenish slates and graywackes 2000 metres or more in thickness. The folding and crumpling is complicated, and partly due to lateral compression during earliest Mississippian time, partly to renewed movement in late Tertiary time. Besides the folding, several oblique thrust-faults and thrust-folds were found, representing a push towards the eastern foreland.

The most interesting part on the western border of the Precordillera was found at Barreal, at the side of beautiful irrigated plantations, and has already been described (Heim, 1945). Suffice it to say that after discoveries by A. L. Du Toit (1929), J. Keidel (1922, 1938) described inclined and horizontal thrusting of a Carboniferous series upon Permian, in contradiction to observations of Du Toit, who had only found autochthonous unconformities. My observations have definitely proved the correctness of Du Toit's interpretation, and this was furthermore confirmed by later palaeontological finds and researches made by the Argentine geologists and palaeontologists Harrington, Leanza and Frenguelli. Thus, the lower series is Mississippian, the upper, one of the supposed thrust-sheets, is Pennsylvanian. The unconformities are as follows:—

(1) The Pennsylvanian (Paganzo II) reposes uncomfortably upon a regular upright anticline of marine Mississippian with its tillites.*

(2) The Permo-Triassic, consisting of a basal conglomerate and porphyry lavas, overlies unconformably, partly at right angles, the Pennsylvanian.

(3) The Jurassic and Cretaceous are missing, and the Pliocene, where the contact is exposed, overlies the older formations unconformably.

(4) The uplifted Pleistocene conglomerate covers the older formations unconformably.

We shall now glance at the eastern border of the Precordillera, at the wide valley of the lower San Juan River and the Sierras pampeanas which emerge from the Pampa. Excellent exposures are found on the west side of the railway Mendoza—San Juan near the stations Carpinteria and Rinconada. This border region of the Precordillera is called the Rinconada. Fig. 1 is one of a series of sections from a manuscript delivered to the Dirección de Minas of Buenos Aires in April 1946.†

The extraordinary features of this eastern part of the Precordillera are as follows:—

(1) A basement is made of steeply erected and intensely crushed tectonic scales of Ordovician limestone in the form of local thrust-sheets, lenticular bodies and isolated blocks of all sizes up to hundreds of metres in thickness and over one kilometre in length, all enveloped in Devonian slates. Already at a long distance from below and from the air, these white limestone inclusions stand out from the dark Devonian slates. In some cases, intermediate though tectonically reduced layers of Gotlandian slates appear between them. Where the contacts are exposed, tectonic striation or polishing may be seen on the surface of the limestone. In addition to the scales of Ordovician limestone, there are intercalations in the Devonian of coarse conglomerates with limestone and quartzite pebbles, in the shape of squeezed layers or blocks.

* Details of the Mississippian glaciation are given in my paper presented to this Congress: *Observations on the Glaciation of South America as related to tectonics.* Eclogae geol. Helv. 1951.

† Meanwhile published and issued (Heim, 1948).

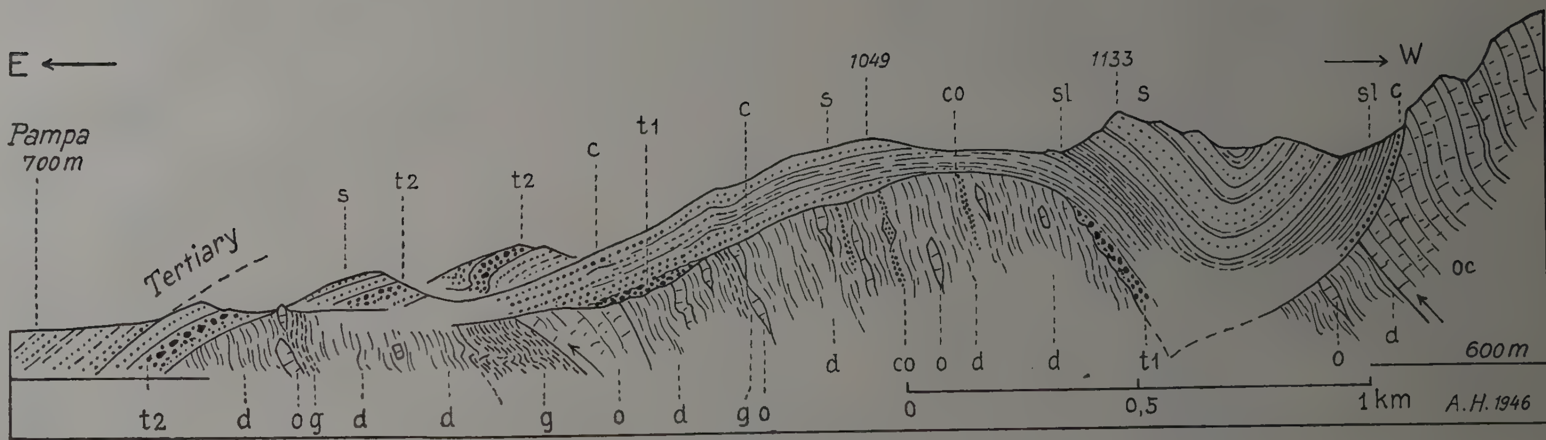

FIG. 1.—*Section of the eastern border of the Precordillera de San Juan, region of La Rinconada, about 35 km. S. of the city of San Juan.*

oc=Cambro-Ordovician limestone; o=scales and lenses of Ordovician limestone, partly fossiliferous; g=variegated schists and quartzites of Gotlandian; d=slates and graywacke sandstone of Devonian; co=coarse quartz conglomerate with large pebbles of Ordovician limestone and quartzite, uppermost Devonian or lowest Mississippian; t^1 and t^2= Mississippian tillites (moraines); c=conglomerates, partly fluvioglacial; s=sandstones and sl=dark slaty shales of Mississippian with plant remains.

(2) The boundary of this complex border region of La Rinconada against the inner part of the Precordillera is determined by a steeply inclined overthrust of the great Cambro-Ordovician limestone formation which forms the first high border range of the Precordillera (Fig. 1).

(3) The Mississippian formations rest in complete, in parts rectangular, unconformity upon the older Palaeozoic basement, and are not thrust upon it.

(4) This unconformity as well as the overlying Mississippian formations of tillites, conglomerates, sandstone and Carbonaceous slates form a beautiful upright anticline and syncline upon their basement.

(5) The coarseness of grain of these sediments, with the exception perhaps of the basal tillite which is absent at the anticlinal axis, increases in general from west to east.

(6) The contact of the Mississippian with the Tertiary (chiefly Pliocene " Calchaquies," consisting of alternating red sandy clays, sandstones and conglomerates) was found to be an unconformity marked by little or no difference of dip.

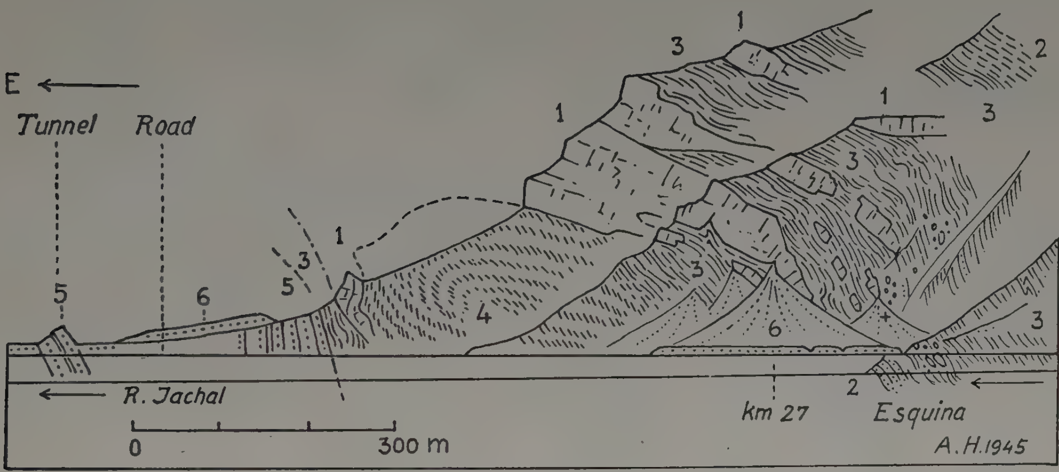

FIG. 2.—*Section of part of the eastern side of the Precordillera of San Juan on Rio Jachal, Dep. San Juan, Northern Argentina.*

1=Ordovician limestone; 2=variegated slate and quartzite, Gotlandian; 3=phyllite, Devonian; 4=black shale with alum efflorescence, showing cleavage, apparently Mississippian; 5=sandstone, Paganzo II, upper Pennsylvanian; 6=Quaternary gravel and fan deposit.

(7) Thus, the younger folding affecting the Mississippian formations is of latest Tertiary age. There are indications that this tectogeny continued into the Pleistocene.

Other curious phenomena were observed in the northern continuation of the Precordillera where it is cut across by the Rio Jachal, 150 km. north of San Juan (Fig. 2).

The extraordinary and partly unexplained observations may be summarized as follows:—

(1) The Ordovician limestone is found in all shapes and sizes from small pebbles to huge blocks.

(2) The smaller blocks and pebbles are enveloped in slate of Devonian type.

(3) At the esquina (+ in Fig. 2), below and above the road, the larger blocks show striation, friction and squeezing.

(4) The smaller inclusions in the slate are made of rounded and angular stones derived from the older Palaeozoic, namely Ordovician limestone (predominant), black flint (Ordovician) and more or less sandy and dolomitic limestone and quartzite of Gotlandian type.

(5) These pebbles form true conglomerates in places along the road. Above it (at + in Fig. 2), the round pebbles attain the size of ½ to 2 metres in diameter. They are embedded in Devonian slates.

(6) The tectonic compression and squeezing is such that glacial striation could not be ascertained. It thus remains questionable whether the coarse conglomerates are glacial or not. (At the Rinconada round pebbles were found in the Devonian which show traces of glacial striation.)

(8) The substratum, upon which this Ordovician limestone is apparently thrust, consists of cleaved though otherwise unmetamorphosed bituminous clay shale apparently of Mississippian age.

(9) In a slightly reversed attitude, outside the reduced zone of limestone, there is a squeezed and reduced zone of Devonian slate (Fig. 2).

This section of the Precordillera thus shows a twofold difficulty of interpretation; it presents both a stratigraphic and tectonic problem. To solve it, the first necessity would be photogrammetric mapping on a scale of about 1:10,000, then geological mapping over a wider area. If my tectonic interpretation so far is correct, the described Jachal section of the Precordillera shows a locally inverted anticline, with a nucleus of a formation younger than its limestone envelope.

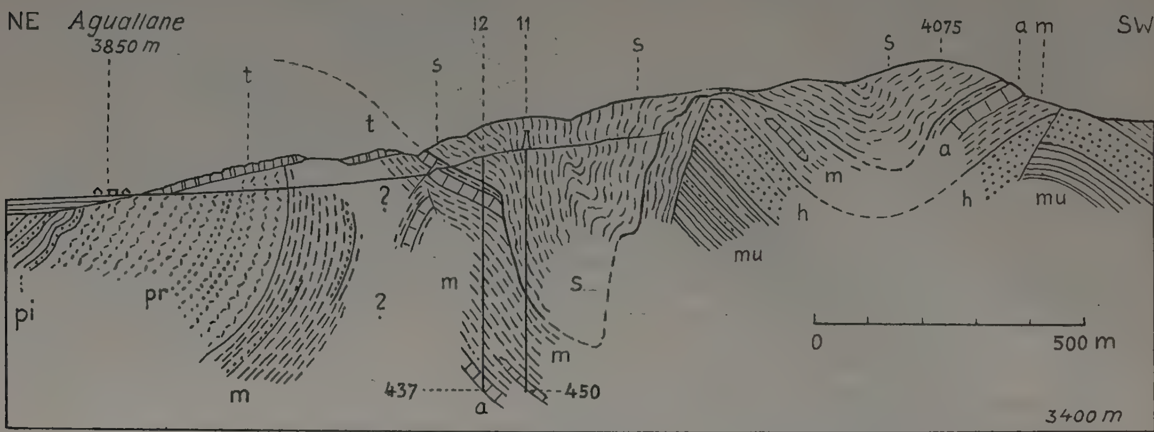

FIG. 3.—*Section of part of the oilfield of Pirin near Pusi, north-west of Lago Titicaca.*

mu = Muni formation; h = Huancané sandstone; m = Moho formation including a = Ayavacas limestone (several stratigraphic repetitions); s = Sipin limestone; pr = Pirin breccia; pi = sandstone, Tertiary; t = travertine, Pliocene (names proposed by Newell).

REGION OF PIRIN, LAKE TITICACA, PERU

Extraordinary, though autochthonous, complications were found, while studying the economic possibilities of the old oilfield of Pirin, in the mountain range on the north-west side of Lake Titicaca.

Extensive investigations had previously been made by Dr. Normann D. Newell of the Museum of Natural History and Columbia University of New York, on behalf of the Peruvian Ministerio de Fomento in Lima. His results were partly published (Newell, 1945, 1946a and b), and partly left to the Government of Peru in the form of a long report and a detailed 1 : 10,000 geological map. When in Lima in May 1947, Dr. Newell kindly showed me the manuscript of a further large and beautifully illustrated volume to be published in U.S.A. in which, in spite of my previously written objections, he had maintained his conception of thrusting. My views having since been published (Heim, 1947), it is only necessary to mention some critical facts and deductions.

In his papers, Newell claims to have established several overthrusts. To the most important he gave the name of Llocamalla after the highest (and unfortunately for Newell an autochthonous)

mountain of Pirin. He postulated a reversed and thrust-sheet of essentially horizontal position which covers more than 100 square kilometres (Newell, 1945, p. 50; and 1946, p. 364).

First, Newell is to be credited for establishing the Tertiary age of the border formations of Pusi, a series of sandstones and conglomerates, which were regarded by Peruvian geologists as Palaeozoic. Also he found a marginal thrust-fault bringing the Cretaceous upon this steeply erected and partly overturned Tertiary series. But his conception of the great horizontal Llocamalla thrust-sheet is certainly wrong, and seriously affected judgment of the oil possibilities. Fig. 3 may help to explain the complicated structure.

Of these formations, Newell regarded mu, h, m and a as Middle Cretaceous. The Sipin, considered as Lower Cretaceous by Newell, would be thrust over the younger Cretaceous formations in a flat position. To this, it must in the first place be objected that there are deep and narrow synclines of the Sipin. In several places, the exact contact of the Sipin upon its substratum was found naturally exposed, or was opened. In no such place was any sign of thrusting found. No doubt can remain that the Sipin is overlying its basement, the relation being one of regional autochthonous unconformity, and that it is younger than its substratum. All over the ranges of Pirin and surroundings, the Sipin shows a great stratigraphic overlap from the Devonian to the Cretaceous.

This interpretation is proved by well No. 11 of the Ministerio de Fomento; instead of passing the supposed overthrust and striking an oil horizon, it entered the deep syncline and only passed through it at 271 metres depth.

It is concluded that the Llocamalla thrust-sheet does not exist.

The extraordinary feature of the north-western border range of Lake Titicaca is not thrusting, but enormous autochthonous local complication resulting from the superimposed unconformities, and the different phases of folding and crushing. The Ayavaca limestone, which in its type locality Ayavacas on the road from Juliaca to Taraco is stratigraphically four times superimposed on the red argillaceous Moho, is frequently broken and torn into blocks and lenses of all sizes, which often make it impossible to draw correct sections. The local strikes are in all directions. A feature apparently unknown before is the longitudinal stretching of isolated tectonic blocks, as revealed by horizontal striation by friction, in the general direction of the strike. These deformations were made under the pressure of the former cover, which, however, was insufficient to cause metamorphism except local calcification in places of greatest deformation.

General Considerations

In all the Andean regions which I have studied, there is nothing similar to the Alpine type of thrusting, though great complications result from the autochthonous compression with folding, crushing, crumpling, thrust-faulting, scaling and fracturing. The local complications may be no less than in the Alps and equally difficult to decipher, though of quite different type.

(*a*) In addition to the normal folding and faulting there are complications by unconformities with intermediate phases of erosion and renewed tectogenesis (Heim, 1945, 1947a and b, 1949).

(*b*) Disturbances and complications due to widespread igneous intrusions, both batholithic and extrusive. They cause oblique and transverse deviations of the strike, which make it impossible to draw proper sections.

(*c*) Contact metamorphism may be so extensive that it is difficult to recognize the age of the formations. This, for instance, is the case around the batholiths of Cordillera Blanca and its northern continuation, where the Mesozoic formations are metamorphosed into semi-crystalline andalusite-schists.

(*d*) The folds or faults may be inclined either to the west or to the east. This demonstrates that, in contrast to the Alps, there is no unilateral push from the Pacific or from the Brazilian shield. The Andes were compressed from both sides. This finally resulted in a general uplift, while the adjoining regions, namely the Pacific coastal trough and the Amazon side, were and still are, subsiding.

(*e*) Although many geologists are fond of inserting faults to overcome discordances or lack of observation, I have been surprised at the scarcity of large-scale faulting in the Andes. Even the common small discontinuities are frequently caused by unconformities rather than by faulting. A striking example is provided by the Sierras pampeanas in the Department of La Rioja, Argentine. Groeber, on a generalized map, has represented this region as dominated by block faulting. My observations on the contrary have established in numerous cases the existence of clear symmetrical and asymmetrical folds of Carboniferous to Triassic strata (Gondwana facies), with anticlinal cores of older crystalline rocks. This is nicely demonstrated by the arches formed by the sedimentary covers surrounding the crystalline cores where there is axial pitch.

(*f*) The stratigraphical divisions are frequently devoid of fossils and are of enormous thickness. Thus, the Devonian in Northern Argentina, Bolivia (Ahlfeld, 1946) and Peru is several kilometres thick and is very widely extended by repeated close folding. On the Urubamba river in Peru, for instance, the steeply erected Devonian was found uninterruptedly over a width across the strike of about 130 kilometres. The age is only determined by its facies. In the northern Peruvian Andes, the marine Cretaceous and Upper Jurassic are more than 5 km. thick. The Tertiary red beds on Rio Urubamba were found to exceed 6 km. (Heim, 1948). To explain such accumulations, long and large subsidences must be supposed.

The great high plane of Bolivia and Peru (Puna, Altiplano) as well as the lower terraces of the Pacific slope of the Andes (tablazos) are testimonies of the general Plio-Pleistocene uplift. Numerous observations point to the assumption that this movement is still going on, while both sides of the Andes are subsiding. The trough along the Pacific coast of 6000 metres depth and more is counterbalanced by a corresponding uplift of the Cordillera. The frequent and often destructive earthquakes of Chile, Argentine and Peru as well as the tremendous erosion and rock falls are remarkable testimony that mountain making in Andean South America is in rapid progress.

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THE GLACIO-FLUVIAL AND GLACIO-EOLIAN DEPOSITS OF THE CONTINENTAL GLACIERS

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ABSTRACT

Deglaciation of the existing continental glaciers proceeds through downmelting from their surface during summer seasons. The meltwater issues from beneath the glacier front highly charged with detritus of all sizes from silt to boulders, the latter carried out in small bergs detached from the ice face through undermining.

According to the general slope of the periglacial area, the silt, sand, and pebbles suspended in the meltwater are deposited in a flood plain (outwash apron) off the glacier front, or else are largely carried away in either outward flowing or marginal rivers which flow only during the summer months. In winter seasons the dried out outwash apron becomes a deflation area with the silt deposited outside as a wide encircling apron of loess. Boulders stranded on the outwash are drilled into ventifacts by the flying sand. Such glacio-fluvial and glacio-eolian deposits occupy the same relative positions off the margins of the Pleistocene glaciers.

Wherever with slope toward the glacier front marginal meltwater rivers have formed, they have during the summer seasons accomplished profound erosional and depositional changes on their way to the sea. This is illustrated by the Mississippi River, which carried the meltwater from four successive glaciations.

THE GLACIAL DEPOSITS OF A FIRST GLACIATION

ALL continental glaciers pass through two periods. These are: first, that of initiation and growth to the maximum size; and second, their liquidation or deglaciation. These are respectively the *advancing* and *receding* hemicycles of glaciation. During the first of these the glacier as its front advances ploughs up and scrapes off the loose material that it overrides, after mowing down and crushing the forests along its path.

If it is a first glaciation of the region covered, it is the mantle rock or regolith of secularly weathered loose material which is gathered up to be laid down beneath the glacier nearer its front. There results a glacial till which contains much organic matter—soil, roots, branches and stumps of trees—and is dark in colour as well as cemented into a hard mass termed colloquially hardpan. Under the weight of the glacier the harder residuals of the regolith have planed off, polished and striated the underlying bedrock and given it a *glaciated* surface. If areas of crystalline rocks, such as granite, gneiss and quartzite, have been passed over, the great ellipsoidal blocks which had resulted from their secular weathering are carried forward at or near the glacier front but without having been overturned, for they are found to be glaciated on a single surface only, that on which they later rest. Further evidence of this is that they are seldom found in the till, but on the outwash, whither they have apparently been ice-rafted in the bergs floated out from the glacier front. To such gigantic blocks after their transportation I have given the name saxum (Hobbs, 1947, fig. 1). The characteristics of the tills from initial glaciations in comparison with those of later ones have recently been illustrated by a study of the deposits from the four succeeding glaciations of North America, the tills of which are all of them exposed within the state of Iowa (Hobbs, *op. cit.*).

CONTINENTAL GLACIERS ARE PROGRESSIVELY LIQUIDATED FROM THEIR UPPER SURFACES

Liquidation of a continental glacier proceeds progressively downward from its upper surface, not backward from the front, as it does for alpine glaciers. This has been shown by study of the existing continental ones, both of which are to-day in the receding hemicycle of glaciation. The

intrafrontal zone of the Antarctic glacier to the west of McMurdo Sound has already had its surface lowered by not less than two thousand feet (Taylor, 1914, 1922).

THE GLACIO-FLUVIAL AND GLACIO-EOLIAN DEPOSITS ARE LAID DOWN ON THE PERIGLACIAL AREA

A study of the deglaciation of the Greenland glacier and the resulting formation of glacio-fluvial and glacio-eolian deposits on the periglacial area off its front was carried out in the years 1926 to 1928 (Hobbs, 1931 (a) and (b), 1942, 1943).

The melting on the glacier's surface goes on only during the summer seasons. Explorers who penetrate Greenland's interior area between July and September find the glacier's surface for a distance of some tens of miles from the front covered over by lakes and rivers of melt-water, the rivers flowing outward down the sloping ice surface toward the front and before reaching it cascading into cracks in the ice (*crevasses*) to melt their way through subglacial ice tunnels and issue from beneath the front under hydrostatic pressure and with a strong current (Fig. 1, map at left). Highly charged with detritus gathered up from the bottom and from the debris-laden lower layers of the ice itself, these outflowing streams of braided pattern lay down an out-wash plain (*outwash apron*) made up mainly of sand, gravel, and silt, but with some clay.

During the mid-summer days the outflowing meltwater is so copious that the plain is usually flooded throughout, but by evening the melt-water is generally held within the braided channels. From time to time the glacier front becomes sufficiently undermined to detach bergs which are heavily

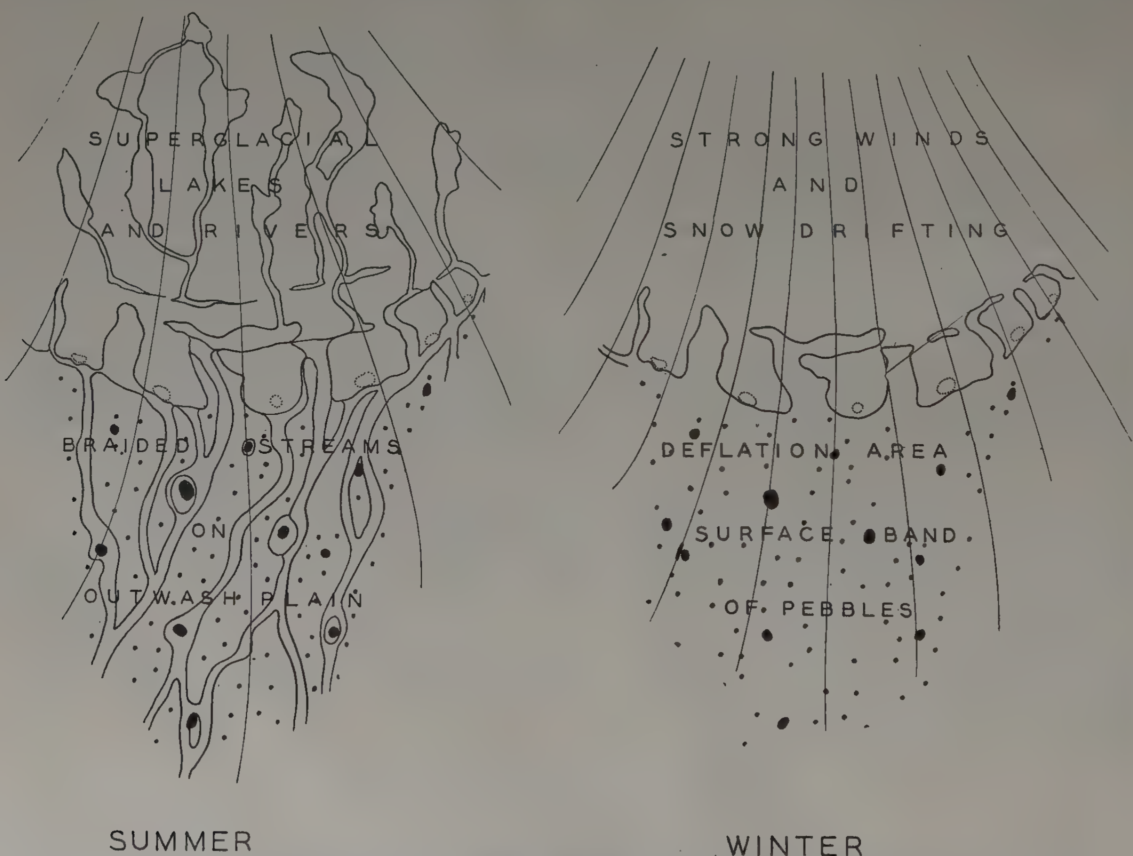

FIG. 1.—*Schematic maps to illustrate the frontal zone of the Greenland glacier and its periglacial area during deglaciation.*

laden with debris in size up to boulders several feet in diameter. These bergs are either carried out to the sea in the channels, or are drifted laterally in the floods to become stranded upon the plain. There the ice is slowly melted to leave the boulders as well as much finer material.

At the close of the summer season (early September in south-west Greenland) all melting of the glacier ceases, the surface layers of the outwash apron then quickly dry out, and this now dried material becomes the prey of the strong outblowing winds off the glacier. The plain of glacio-fluvial materials is now a deflation area. Silt, sand, and even pebbles are lifted, carried out across the plain, the pebbles by saltation near the ground, the sand as well, but horizontally, mainly within a yard of the surface, and the silt up to high levels. The sand is laid down in dunes at eddied places after drilling the stranded boulders into ventifacts. The silt is caught and held by the tundra vegetation off the borders of the plain,

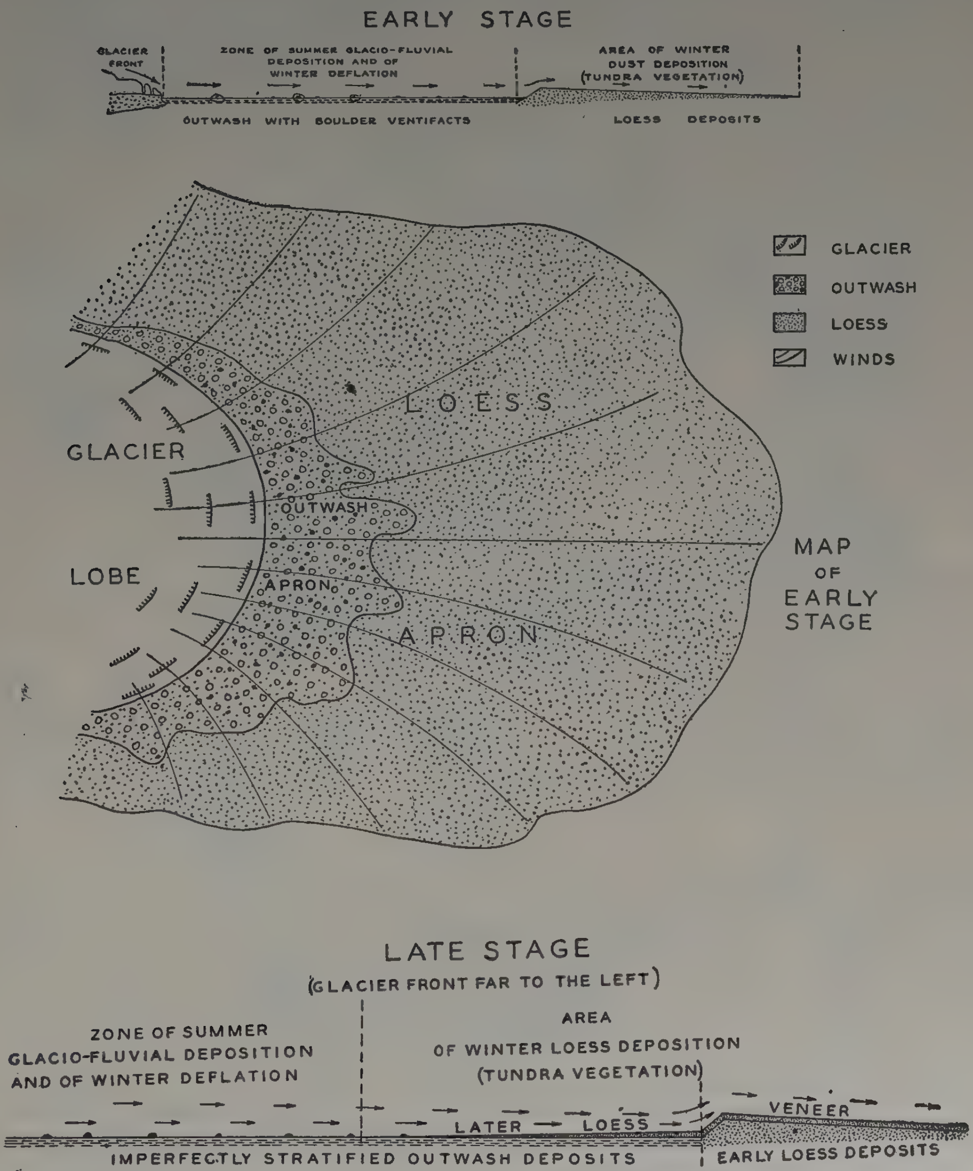

FIG. 2.—*Plan and profiles of the aprons of glacio-fluvial and glacio-eolian deposits off the front of a continental glacier.* (*After Hobbs,* 1947, *p.* 11.)

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FIG. 3.—*The latest Wisconsin glaciers in the Northern Hemisphere.*

Their contemporaneity in the Eastern and Western Hemispheres is shown by the essential identity of the vertebrate remains entombed in the outwash and loess deposits. The Siberian part of the map is based on a recent Soviet Atlas.

where it builds up a heavy outer apron of loess that is thickest next the plain and thins out gradually for the distance of a hundred miles or more (Fig. 1 at right and Fig. 2) (Hobbs, 1943, pp. 368–382, maps 1–2, Figs. 1–18). The pebbles of the outwash which are too large to be lifted soon collect and form a surface armor (" *pebble band* ") to the outwash plain and this halts the deflation process by protecting the material below.

The next succeeding summer the meltwater floods over the outwash, redistributes the pebbles of the surface pebble band, and their whirling currents move the stranded boulders about, thus retaining them always on the surface of the plain as it rises, and preparing them to expose a new surface to the bombarding sandblast of the next succeeding winter. The final form of the boulders thus tends to be ellipsoidal, and the completed plain has a top pebble band with ventifact boulders scattered over its surface. These characteristics of an outwash plain and its encircling apron of loess are of great aid in recognizing the glacio-fluvial and glacio-eolian deposits of the continental glaciers of the past, and especially the latest one, where they are well exposed for our inspection (Fig. 3).

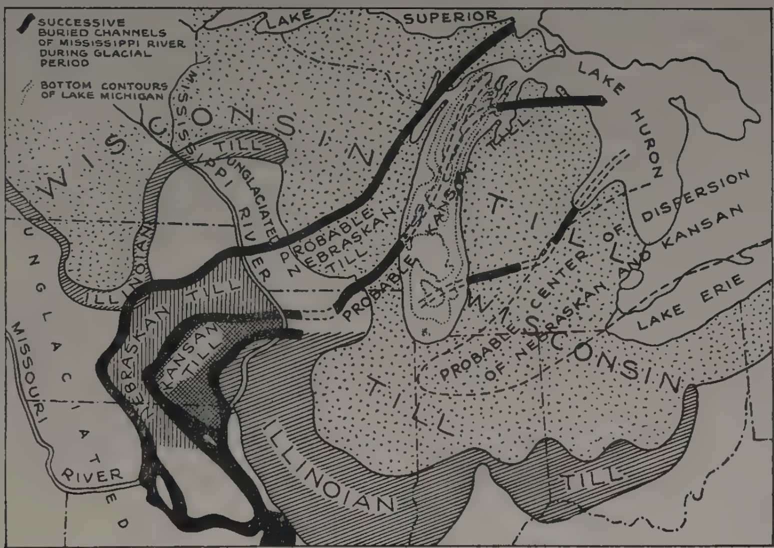

FIG. 4.—*Glacial map of a central portion of the glaciated area of North America.*

The marginal meltwater rivers of the three earlier glaciations are shown in black somewhat exaggerated in width. The newly discovered Late Illinoian glacier lobe and the overlying Late Wisconsin Lobe both have extensive outwash and loess aprons, one superimposed upon the other, but in the interest of the clarity of the map they are omitted. (After Hobbs, 1947.)

It must be clear that plains of outwash can be built up off the front of continental glaciers only where the general slope of the periglacial area is in a direction away from the glacier front. In the case that it is toward that front, a marginal meltwater river will hug the border of the ice. No well established present-day river of this nature has thus far been reported, though they probably exist. A small section only of the marginal area of the Greenland glacier has been reported upon with this in mind, and the only possible known periglacial areas of the Antarctic are the " oases " reported by " Operation Highjump," recent national expedition commanded by Admiral Byrd (Byrd, 1947).

Though we have not yet discovered existing marginal meltwater rivers, excellent examples are supplied by each of the three earlier Pleistocene glaciers of North America. These glaciations are the Missourian (formerly Nebraskan), Iowan (formerly Kansan), and Illinoian (Fig. 4). These rivers received meltwater only during the summer, and were of relatively small volume in winter, when they carried only the surface water of direct precipitation. The bottom deposits which were exposed during

the early winter became the prey of the outblowing winds of the glacial anticyclone, and hence they laid down aprons of loess, though because of the smaller area exposed these loess deposits were much less heavy than those which surround outwash plains.

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DEEP-SEATED CRUSTAL DEFORMATIONS IN A NORTH-WESTERN PART OF THE CALEDONIDES OF SOUTHERN NORWAY

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ABSTRACT

Passing from the Oslo district northwards across the mountain mass of Southern Norway one meets with a number of structurally and petrologically different zones which correlate more or less with the Alpine ones from the Jura Mountains to the belts of crystalline rocks bordering on the north-west part of the North Italian Plain. West of the synclinal Trondheim district, with Cambro-Silurian schists matching the Mesozoic *schistes lustrés* of the Pennine zone, crystalline masses, which in geological maps generally have been classified as Archaean, appear in a large culmination-area. It has been proved that highly metamorphic Trondheim schists as well as "Eocambrian" psammitic rocks make up considerable parts of these masses and furthermore that the orogenetic structure is largely characterized by recumbent folds. Crystalline basement masses, mostly granodioritic gneisses, have also been subjected to this folding. They have behaved plastically and correspond to the cores of the Pennine nappes. The "basal gneisses" occupy stratigraphically the position of the original Archaean, and remains of a conglomerate have locally been found at the upper boundary, but they have to a considerable extent obtained their present petrological character in Caledonian time.

IN a paper dealing with various problems of the Scandinavian Caledonian zone, read at the "Nordiska Naturforskarmötet" in Helsingfors in 1936 (Holtedahl, 1936), I discussed briefly some points of similarity between this orogenic zone, especially as it is developed in Norway, and that of the Alps. Attention was drawn to a number of parallel features both as regards the general character of the sedimentary rocks, and the tectonic structure.

Here I intend to follow this comparison a little further, pointing especially to conditions found since then in a district of Southern Norway which in various ways corresponds to parts of the Pennine zone of the Alps. It may, as an introduction, be of interest first briefly to consider other, more peripheral zones, as we meet them in a S.–N. section from the Oslo fjord northwards across the mountain mass of Southern Norway.

(1) The likeness between the Caledonian structure of the Oslo district and the structure of the Jura Mountains is very striking. The marine Cambro-Silurian sediments of the Oslo district, about 1000 m. thick, correspond to the Mesozoic ones of the Southern area. In both areas the marine beds consist largely of shaly and marly material, interbedded with limestone. The folding has been a "*plissement de couverture*," a superficial folding, with minor overthrusts, and dying out peripherally. It has generally not affected the basal part of the sedimentary series which lies protected by the undeformed crystalline basement.

(2) Along a line crossing the northern part of the large Norwegian lakes Randsfjord and Mjösa we meet the big thrusts, with quartzitic sandstone, which represents the youngest part of the so-called "Sparagmite Formation," thrust southwards above the basal remains of the Cambro-Silurian. This front corresponds to the front of the Helvetic zone of the Alps.

The Sparagmite formation is principally built up of coarse clastic rocks, largely feldspathic sandstones ("sparagmites") which over wide areas of the Caledonian zone of the Scandinavian peninsula underlie, without any structural unconformity, the Lower (fossiliferous) Cambrian. In Norway, we use for this series of coarse clastic sediments, which rests with a very marked unconformity on pre-Sparagmitian rocks, the term "Eocambrian" (a word introduced about 50 years ago) because

stratigraphically and tectonically this series is closely connected with the Cambro-Silurian. It represents the oldest deposits of the Caledonian cycle and belongs structurally to another system than the youngest pre-Sparagmitian sediments, the " Jotnian " sandstone series.

It should be emphasized that Eocambrian sediments, containing tillite deposits in the upper part, form a characteristic and important member of the rock complexes of the North Atlantic Caledonian belts. They are now known to exist also in Scotland, Spitsbergen and East Greenland.

In the paper mentioned above I compared the Sparagmite Formation to the Permian *verrucano* of the Alps. It is a feature common to both the Sparagmitian series of the Scandinavian districts and the *verrucano* that the thickness shows a marked and often rapid variation. Both series are mainly of a coarse, detrital type and denote a breaking-down of crystalline masses which must have been subjected to erosion through crustal movements, possibly of a more or less irregular type.

In the Swiss Alps the *verrucano* occurs with an especially great thickness in the Glarus district, amongst others in huge nappes thrust above younger sediments, and carrying other younger sediments (Triassic and Jurassic) in the same way as the thrust and somewhat metamorphosed sparagmites of the Gudbrandsdal district of Norway are capped by remains of Cambro-Ordovician phyllites. These phyllites represent a facies more pelitic than that of the peripheral zone, mentioned above, and differ from the facies met with further north in containing no volcanic material.

The volcanic rocks, which are so typical of the Permian of the Alps have, as far as we know, no parallel in the Sparagmitian of the Scandinavian peninsula, but it should be emphasized that in N.E. Spitsbergen a volcanic series with porphyries, etc. (the Cape Hansteen formation) underlies the Eocambrian sediments, making up the lower part of the so-called Hecla Hoek series.

(3) The curved row of " Central Massifs," Mt. Blanc, Aar-Gotthard, etc., correspond in the Scandinavian district under consideration to a number of upfolded or locally thrust crystalline masses which are exposed in the northern parts of the sparagmite region. These masses have to a large extent been subjected to intense shearing in Caledonian time. Sparagmitian rocks, developed as sparagmite schists, have moved southwards above them.

(4) Inside this row of culminations we have in the Alps the Pennine zone, typical of which are the *schistes lustrés* (*Bündnerschiefer*) with large masses of metamorphosed basic volcanic and intrusive rocks (ophiolites). In southern Norway we have as a parallel the Cambro-Silurian " Trondheim Schists," consisting largely of more or less metamorphosed pelitic and volcanic rocks. Especially in the north-western districts thick masses of pillow lava of Lower Ordovician age occur. Serpentine bodies are characteristic of the lower part of these schists. Between this schist series and the crystalline " massifs " mentioned above come thrust metamorphic sparagmites. Conditions recall especially those at the eastern end of the Gotthard massif, with a zone of *verrucano* between the latter and the Pennine schists.

West of the Trondheim depression we have the large culmination area which in its central part is cut (in a N.W.–S.E. direction) by the Romsdal valley. The crystalline rocks, mostly gneisses of various types, which are exposed here, have up to fairly recent time generally been regarded as pre-Sparagmitian (Archaean) and classified as such in geological maps. The prevailing opinion has been that we have here a somewhat upfolded mass of a rather compact basement complex. It should, however, be mentioned that Törnebohm in maps of 1896 and 1908 marked patches of his " Seve Group," which *inter alia* includes Sparagmitian rocks, in eastern parts of the district, that Carstens in 1924 reported the occurrence of sparagmite rocks in one part of the eastern margin of the area (Trollheimen district) and C. Bugge, in 1935, reported green Trondheim schists near Molde in the Romsdal district, and that, furthermore, Wegmann (1935) and Backlund (1936) have considered this Romsdal gneiss region to have been strongly influenced by Caledonian orogenic processes.

Judging from a few scattered personal observations and from the study of literature, I expressed in the paper of 1936 the opinion that, in the district under consideration, probably both Eocambrian and Cambro-Silurian sediments have, to a large extent, undergone gneissification and granitization processes which have altered them into rocks of "Archaean " appearance.

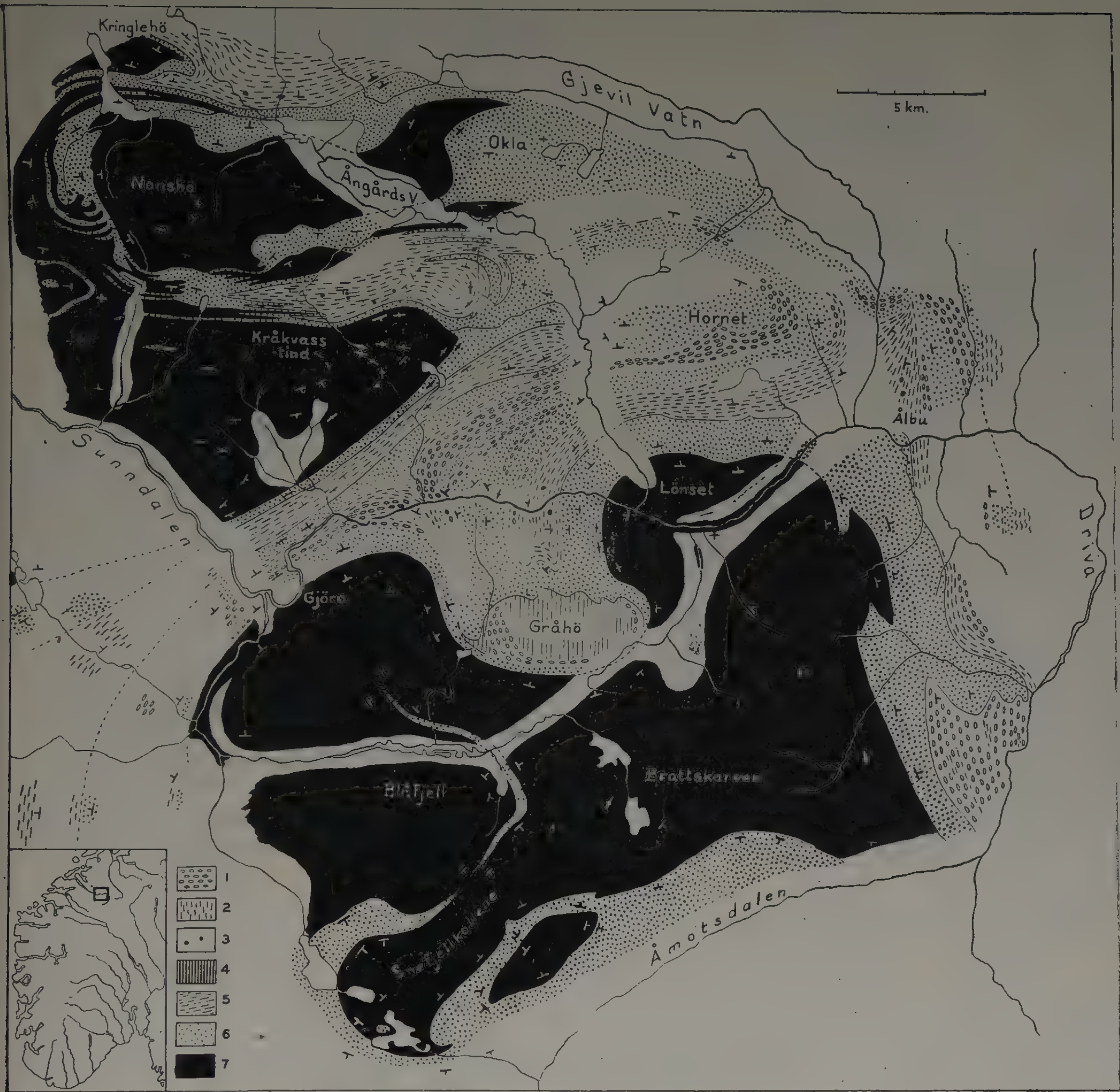

FIG. 1.

The western part of the area of map sheet "Opdal." The north-western districts, north of the river Driva west of Lönset, have been geologically mapped by H. Holtedahl, the other parts by I. T. Rosenqvist and O. Holtedahl, with contributions also by J. Dons and O. F. Edwin. By permission Norges Geologiske Undersökelse.

Key to Legend:—

1. Augen-gneisses (locally also biotite-gneisses of other types) above "basal gneiss" complex.
2. Less highly metamorphic "Trondheim schists" (phyllites, etc.) of eastern district (main Trondheim depression).
3. Serpentine bodies.
4. Large gabbro-mass of Gråhö with schistose peripheral zone.
5. Highly metamorphic "Trondheim schists": mica- and hornblende-schists, with more massive rocks of gabbro-character.
6. Eocambrian: metamorphic sparagmite (mostly flagstone rich in muscovite), in northern districts also quartzite.
7. "Basal gneiss" complex: granodioritic rocks, gneiss granites, banded gneisses, augen-gneisses, amphibolites.

During some of the summers since 1936, a particular area just west of the main Trondheim depression, viz. the western part of the map sheet Opdal, has been investigated in some detail, for Norges Geologiske Undersökelse, especially by Ivan Th. Rosenqvist, Hans Holtedahl and myself. Some main features of the geology can be seen from the map, Fig. 1.

Apart from the less metamorphosed schists to the east, we are here dealing with three main stratigraphical divisions: (1) the " basal gneiss " complex; (2) the metamorphic Eocambrian series, with a primary thickness of probably 1000 m. or more, commonly developed as (often gneiss-like) flagstones rich in muscovite; (3) Trondheim schists, mainly mica- and hornblende-schists with, locally, masses of more compact basic rocks undoubtedly intrusive in origin. Very thin zones of coarsely crystalline limestone are met with in places.

As to tectonics the investigations soon showed that overfolding structures were characteristic of the district and several large-scale examples of recumbent folding of the Sparagmite-Trondheim Schist series have been demonstrated. Of great interest is the fact that the basal complex has also partaken in structural deformations of the same type (especially in the Kringlehö district in the extreme N.W.). The " basal gneisses," like the other rock complexes, have evidently been in a state of great plasticity during the deformation.

The structural conditions found in this district recall to a considerable extent those of certain parts of the Pennine zone of the Alps, with overfolded crystalline cores (" *Altkristallin* ") mantled by highly metamorphosed sedimentary rocks. The gneisses of the cores of the Pennine nappes show, in contrast to the crystalline massifs mentioned before, a structure fully conformable to that of the adjacent schists and especially in recent years there has been much discussion as to their true nature. In the Norwegian district under consideration the basement complex shows a similar conformable structure. The rocks are of a somewhat different character in the different areas where the crystalline basement comes to the surface. In a north-western area (" the Nonshö anticline ") we have rather compact granodioritic rocks, usually, however, with increasing foliation (parallel to the upper boundary) as we approach the sedimentary mantle. In the Kraakvasstind area and in the Lönset district the basal complex is much more heterogeneous, with conformable layers of different types of rocks: distinctly banded gneisses more or less rich in biotite, augen-gneisses and amphibolitic rocks, besides relatively massive, yet nearly always distinctly foliated granodioritic rocks. Pegmatite masses and aplitic veins are common.

A most important feature is the occurrence in various places of remains of a more or less strongly metamorphosed quartz conglomerate, at the base of the Sparagmitian psammitic series. This indicates that the basement complex has, stratigraphically, the position of the original, pre-Sparagmitian complex. On the other hand the conformable structure tells us that we are not dealing with the *original* basement rocks. Very considerable changes, not only of a mechanical nature but including also radical processes of mobilization and recrystallization, must, in Caledonian time, have taken place, especially in the distinctly banded rock masses. The augen-gneisses, for instance, must be regarded as essentially " new " rocks.

It should be emphasized that very commonly there is a transitional zone between the " basal gneiss " complex and the Eocambrian series, with biotite occurring in considerable quantity also in rocks belonging to the latter series. In some districts it is impossible to draw a fairly marked boundary line between the two divisions. Rocks rich in biotite and in muscovite may alternate. Such conditions are, at least in some places, the result of isoclinal interfolding.

As regards the mantle of sedimentary rocks, we find here a very high degree of metamorphism. Practically no traces of the original clastic character of the sparagmites can be seen and especially in the north-western part of the area the rocks may have a very coarse, gneiss-like appearance. The muscovite flakes may here reach a diameter of 4–5 mm. The mica- and hornblende-schists of the Trondheim schist series are often garnetiferous and pass into gneiss-like rocks. Besides hornblende-schists with relatively small porphyroblasts of secondarily formed feldspar, we have as very characteristic and widely distributed rocks augen-gneisses telling of most important metasomatic processes.

These augen-gneisses may be very massive and have feldspar augen, mainly made up of potash feldspar, not seldom 5–10 cm. in size. They occur mostly as layers or more lenticular masses interbedded with hornblende-schists. In the Gråhö district we find them in the highly metamorphic schistose peripheral part of the gabbro mass there. Augen-gneisses also occur as intercalations between sparagmite rocks—probably formed in layers of a more or less pelitic character. These metasomatic processes have worked laterally, along the planes of schistosity, in the closest connection with the tectonic movements.

The occurrence of augen-gneiss in layers or irregular masses sometimes hundreds of metres thick is a feature typical not only of the district here particularly dealt with, but, as is well known, also of many other parts of the south Scandinavian region where we find metamorphic sparagmite rocks in large quantities. The idea lies near that a source of the potash necessary for the metasomatic processes in question may be found in the transformation of huge masses of non-metamorphic sparagmite into rocks rich in secondary muscovite.

In some parts of the map area of Fig. 1, we find, in connection with compact bodies of augen-gneiss, massive or slightly foliated rocks of a more typical even-grained granite character. Granite-pegmatite material is commonly met with, both in the Sparagmitian rocks and the Trondheim schists.

For details concerning the petrology of the rock masses under discussion, reference may be made to papers published by Barth (1939) and Rosenqvist (1941, (a and b); 1944) and to a forthcoming paper by Hans Holtedahl.

It may be of interest to mention that also in the " Surnadal syncline " stretching westwards from the main Trondheim depression about 30 km. north of the map area of Fig. 1, highly metamorphosed psammitic rocks, which no doubt correspond to the Sparagmitian of the Opdal district, occur between " basal gneisses " and coarsely crystalline Trondheim (mica and hornblende) schists; the latter are overlain by less altered mostly green chloritic- and phyllitic-schists containing limestone of moderately crystalline character. These schists underlie the Lower Ordovician pillow lavas. The thickness of the Sparagmitian complex varies very much from place to place, undoubtedly because of tectonic deformations. Here too augen-gneisses commonly occur, sometimes in very compact masses.

Returning now to our comparison with the Alps, we may recall the fact that in some very highly metamorphic parts of the Pennine complex, eclogites are characteristic rocks and that in Norway eclogite bodies, though of a different type, occur in huge numbers in the north-western part of the Romsdal gneiss region.

(5) East of the southern part of the (main) Pennine area we meet with the " Lower East Alpine nappes," believed to have their root-zone south of that of the Pennine complex. These nappes (Err, Bernina, etc.) are largely made up of plutonic rocks showing a wide variation of types: granite, diorite, monzonite, banatite, etc., and they have been subjected to large-scale mylonitization, telling of movements of rigid masses at relatively high levels of the crust. Conditions remind one of those typical of the Jotunheimen district of southern Norway, west of the main Sparagmite region, where huge masses of thrust plutonic rocks belonging to Goldschmidt's " Bergen-Jotun group " lie, with thick basal mylonitic zones, above Cambro-Silurian schists. The age relations of these Norwegian rocks are still under discussion.

(6) Regarding the facies of the sedimentary series of the extreme north-western belt of the Caledonian zone of Norway, represented in northern Norway only, very thick masses of compact limestone and dolomite of Cambro-Ordovician age are there typical rocks, associated mainly with mica-schists. In the Alps massive carbonate rocks, largely of Triassic age, are especially characteristic of the East and South Alpine facies, in the Austrides and the Dinarides. In our suggested comparison, the famous Triassic dolomites of South Tyrol might be set parallel to the massive Lower Ordovician dolomites of Bear Island and of the Durness carbonate series of N.W. Scotland.

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DISCUSSION

E. WEGMANN: La communication magistrale de M. Holtedahl est de la plus grande importance pour la tectonique comparée. En effet, la région explorée par une belle équipe de jeunes géologues norvégiens en collaboration et sous la direction de M. Holtedahl, ressemble plutót au style du Tessin qu'à celui du Valais central. Mais pour comprendre ce qui se passe dans l'étage tectonique par exemple du Valais central, il faut connaître les caractères de l'étage au dessous. L'étude des photographies et dessins de M. Holtedahl sera donc indispensable pour les géologues alpins. Les conditions dans la région que nous avons appelé en son temps " la tombée axiale du Drivdalen " sont particulièrement importantes pour l'étude des changements de style dans les différents étages tectoniques.

THE NORTH-WESTERN PART OF THE CANADIAN SHIELD

By A. W. JOLLIFFE

Canada

ABSTRACT

An area of about 130,000 square miles in the north-western part of the Canadian Shield includes four distinct geological subprovinces, each with its characteristic rock types, major fault system, and metallic mineral association. From north to south these are: (1) Great Bear: Proterozoic formations, north-east-trending right-hand faults, and U-Ag-Co-Ni-Cu mineralization; (2) Yellowknife: Archean formations, north to north-west-trending left-hand faults, and Au mineralization; (3) East Arm: chiefly Proterozoic formations, north-east-trending faults, and Cu-Co-Ni-Au mineralization; and (4) Taltson: both Proterozoic and Archean formations, north- to north-west-trending faults, and Ag-Pb-Au mineralization. Each subprovince seems to have had its own geologic history independent of adjacent areas. The metal distribution is considered to reflect original crustal heterogeneities that have persisted throughout geological time since Pb/U ratios indicate that certain uranium deposits within the Great Bear subprovince may differ in age by as much as 1×10^9 years.

THIS paper relates to a Pre-Cambrian area of some 130,000 square miles included in a belt 100 to 300 miles wide that extends for 600 miles along the western edge of the Canadian Shield north from latitude 60° to the Arctic ocean. About half this area has been geologically mapped, chiefly on a scale of one inch equals four miles and, for the most part, within the past 17 years, and probably more than half has been prospected in at least a reconnaissance fashion within the same period. Compilation of the information thus obtained indicates that the region is made up of four distinct units or geological subprovinces each with its own characteristic rock assemblage (Fig. 1), fault system (Fig. 2), and metal distribution (Fig. 3).

The data on which this paper is based were assembled chiefly while the writer was a member of the Geological Survey of Canada between 1931 and 1945 and acknowledgment is made for permission to use them and the accompanying figures.

I. GREAT BEAR SUBPROVINCE

The Great Bear subprovince includes about 50,000 square miles lying east of Great Bear Lake. It is bounded on the south-east by a marked change in the rock types that follows a sinuous course for 200 miles north-north-east from the north end of Great Slave Lake.

The sedimentary and volcanic rocks here are in part younger and in part older than the granitic rocks that make up the greater part of the area, but are everywhere characterized by relatively gentle dips and low-grade metamorphism. For these reasons, and also since many of them resemble late Pre-Cambrian formations elsewhere, they have been assigned to the Proterozoic.* The formations thought to be early Proterozoic in age lie in belts trending chiefly north to north-westerly and consist mainly of thinly-bedded siliceous and dolomitic sediments. Some of the beds contain structures that have been regarded as of algal origin (Fenton and Fenton, 1939; Rutherford, 1929). Minor amounts of volcanic rocks, conglomerate, arkose, and argillite are present. In various districts these formations are known as Snare, Marian, Echo Bay, and Cameron Bay groups. Similar rocks have been found on

* The terms Archean and Proterozoic are used here as synonymous with "relatively early Pre-Cambrian" and "relatively late Pre-Cambrian" respectively. Admittedly the use is subjective but is based on the usual criteria: amount of deformation, degree of metamorphism, relations to major unconformities and batholithic intrusions, lithologic type, etc., (see Alcock, F. J.: Report of the National Committee on Stratigraphical Nomenclature; *Trans. Roy. Soc. Canada*, Section IV, 113-121, 1934).

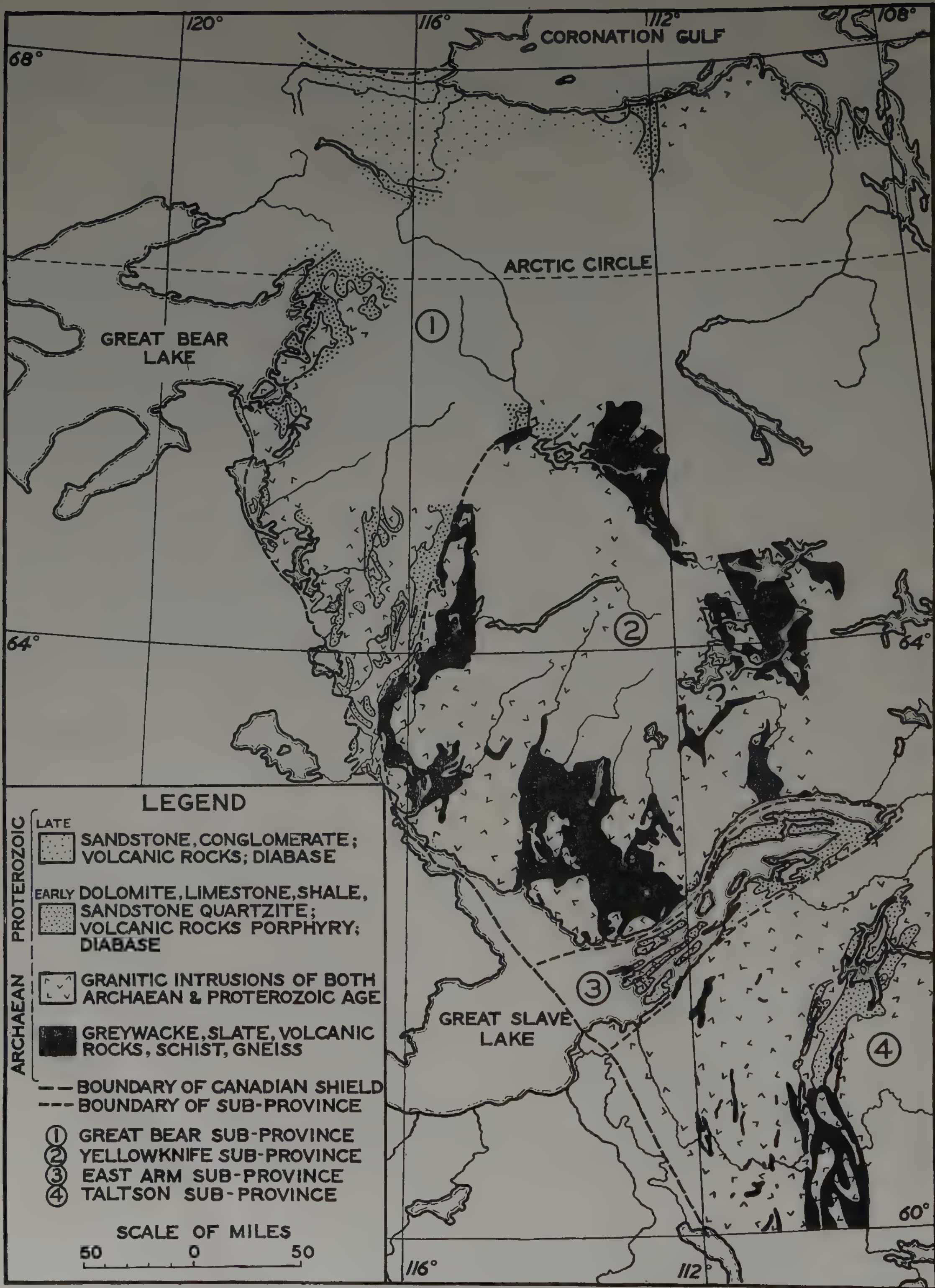

FIG. 1.—*North-west part of the Canadian Shield, showing geological sub-provinces.*

Coppermine River 150 miles south of Coronation Gulf. Farther north the Epworth dolomite carries " concretionary structures " that may be akin to those considered algal in the Snare Group dolomite. The Goulburn quartzite, which overlies the Epworth dolomite in the south-eastern part of Coronation Gulf and exceeds 4,000 feet in thickness, is likewise probably of early Proterozoic age. Intermediate to acid intrusive porphyries are commonly associated with these early Proterozoic formations in the western and southern parts of the Great Bear subprovince.

Nearly horizontal formations assigned to the late Proterozoic include the Hornby Bay and Coppermine River series. The former occurs at the north-east corner of Great Bear Lake and consists of sandstone, quartzite, and conglomerate; the latter is common around Coronation Gulf and may aggregate 48,000 feet in thickness. The lower third is mainly basalt and is succeeded upwards by sandy shale, sandstone, and some dolomite.

More than 30 large quartz stockworks have been mapped in the central and southern parts of the Great Bear subprovince and others are visible from the air as far north as the south-east corner of Coronation Gulf. Some exceed 1,000 feet in width and can be traced for more than 10 miles. Almost all strike about north-east and dip vertically. Several are known to mark major faults along which recurrent movements have brought about right-hand strike separations of up to eight miles. The relative movements have been dominantly lateral for all faults studied in detail.

Characteristic metallic minerals present in the Great Bear subprovince are those containing uranium, silver, cobalt, nickel and copper. The first two metals have been recovered at several mines since production started in 1933.

II. YELLOWKNIFE SUBPROVINCE

South-east of the Great Bear subprovince and extending to the north coast of Great Slave Lake is an area of at least 50,000 square miles throughout which the rock types, major faults, and mineral occurrences are generally akin, but they differ markedly from their counterparts in the adjacent subprovinces.

The oldest rocks are intermediate to acid lavas overlain (in places unconformably) by sedimentary rocks. In the vicinity of Yellowknife these two members aggregate more than 100,000 feet in thickness. The sedimentary rocks are mainly greywacke and argillite, wide areas of which show characteristic alteration to nodular quartz-mica-schist and hornfels carrying chiastolite, cordierite, and other metamorphic minerals. Grain gradations are common in the clastic sediments but cross-bedding is rare. These volcanic and sedimentary rocks commonly dip steeply and, in the southern part of the region, are older than two periods of granitic intrusion. They have been variously termed Point Lake and Yellowknife groups and are considered Archean in age.

Most major faults in the Yellowknife subprovince trend north-west to north and show left-hand strike separations. Large quartz-vein breccias and stockworks that are so common along the Great Bear faults are here relatively rare. The faults have been studied most closely in the vicinity of Yellowknife Bay where, within a belt ten miles wide, they have caused a total left-hand lateral displacement of about 11 miles, nearly half of which occurs along the West Bay—Akaitcho fault.

More than a thousand gold-bearing veins have been found within rocks of the Yellowknife group and are well-distributed throughout the subprovince. In addition, a wide variety of other minerals has been identified including those carrying tantalum-columbium, lithium, beryllium, and tin, which occur in pegmatites associated with the younger granitic intrusives in the southern part of the area. Gold to a value of nearly twenty million dollars has been recovered at the mines of the Yellowknife sub-province since production commenced ten years ago.

III. EAST ARM SUBPROVINCE

The basin of the East Arm of Great Slave Lake includes some 7,000 square miles and constitutes a topographic and geologic unit lying transverse to the prevailing trends in the north-western part of

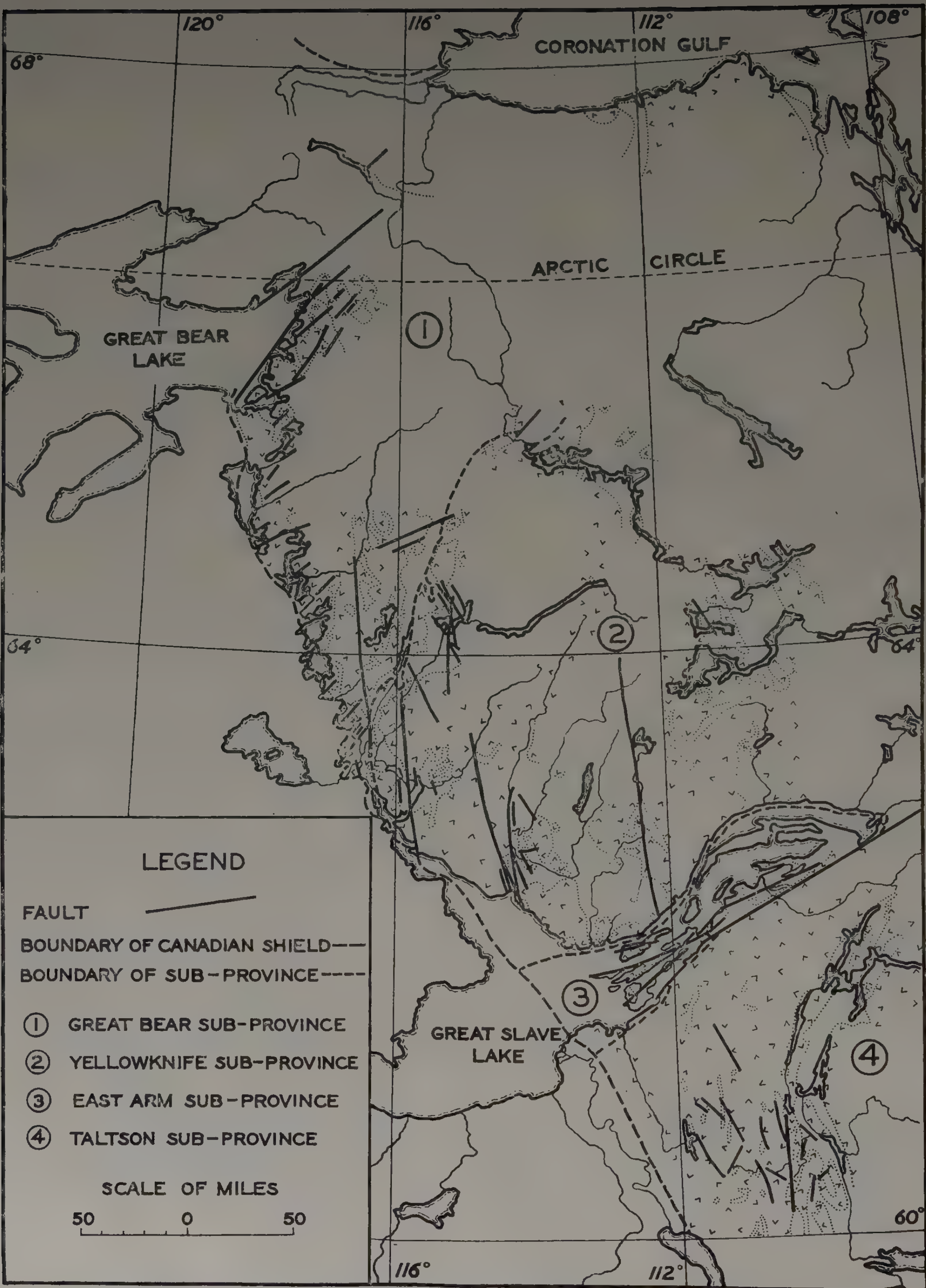

FIG. 2.—*Major Faults. North-west part of the Canadian Shield.*

the Shield, a contrast that is further accentuated by its unique assemblage of rocks, structures, and metals.

The oldest rocks have been called the Wilson Island group; they consist mainly of steeply-dipping, highly altered, conglomeratic, quartzitic, and argillitic sediments with minor acid lavas, dolomite, and lean iron formation, and are considered Archean in age. Ripple-mark and cross-bedding are characteristic of the clastic members. At the type locality their thickness has been estimated as more than 11,000 feet. The Wilson Island group was intruded by granitic batholiths, eroded, and succeeded by a considerable thickness of sedimentary and volcanic rocks known as the Great Slave group and regarded as early Proterozoic in age. The lower part of this consists of quartzose sediments followed by argillite, oolitic iron formation, and dolomite, much of which carries algal structures. The upper part of Great Slave group is dolomite (in part algal), shale, breccia, lavas, and argillite. These formations lie in a synclinorium 150 miles long in an east-north-east direction and up to 40 miles wide. The north limb dips gently but the south limb is closely folded. The Great Slave group is cut by bodies of syenite and diorite, on the eroded surfaces of which was deposited the Et-Then series of nearly horizontal conglomerate and sandstone regarded as late Proterozoic. Great sills and dykes of diabase cut the Et-Then and all older rocks.

The major faults of the East Arm trend about east-north-east. No detailed examination has been made of them but there are some indications that the relative movements along them have been dominantly lateral and right-hand.

So little prospecting has been done in the East Arm that the known mineral occurrences may not give a truly balanced picture of its ores. Copper minerals are, perhaps, the most widespread, followed by nickel and cobalt. Gold, with some tungsten and copper, has been recovered from the one mine of the region which operated in 1941 and 1942.

IV. TALTSON SUBPROVINCE

About 20,000 square miles lying south-east of Great Slave Lake are included in this unit. No detailed geological mapping has been done so that it is the least known of the four subprovinces despite its most southerly position, and its relations with what may be termed the Athabaska subprovince to the south are in doubt.

The oldest formations lie in relatively narrow bands and consist of sedimentary and minor volcanic rocks known as the Tazin series. These bands are bordered by areas of variably intermixed gneiss, schist, and granitic material which grade outwards into relatively pure granitic rocks. The mixed rocks are included with the sedimentary and volcanic bands in Fig. 1, and are all tentatively regarded as Archean. Overlying unconformably all these in a single area of about 1,500 square miles is the Nonacho series of conglomerate, arkose, slate, greywacke, and quartzite. The Nonacho series is cut by younger granitic bodies and is considered early Proterozoic in age.

Most of the known faults and the large quartz stockworks and breccias that probably mark faults trend north to north-west but a few strike about north-east.

Not much prospecting has been carried on in the Taltson subprovince. Lead occurrences appear to be relatively common and most assays for precious metals show appreciably more silver than gold.

The boundaries of the four subprovinces are of various types. The frayed edge of the overlying Paleozoic formations bounds all of them on the west and shows typical glint characters—Shield-facing escarpments, great lakes, and abundant drift cover. In all cases save one the subprovinces are not defined on the east but pass into unexplored territory. The exception is the East Arm subprovince which appears to be confined to the basin of Great Slave Lake, although some of its north-easterly-trending faults probably extend well beyond this. The boundary between the Great Bear and Yellowknife subprovinces is arbitrarily placed at the eastern limit of Snare group rocks (or their corelatives). It has been suggested* that this contact marks the outcrop of a major overthrust, the block to the

* Wilson, J. T., personal communication.

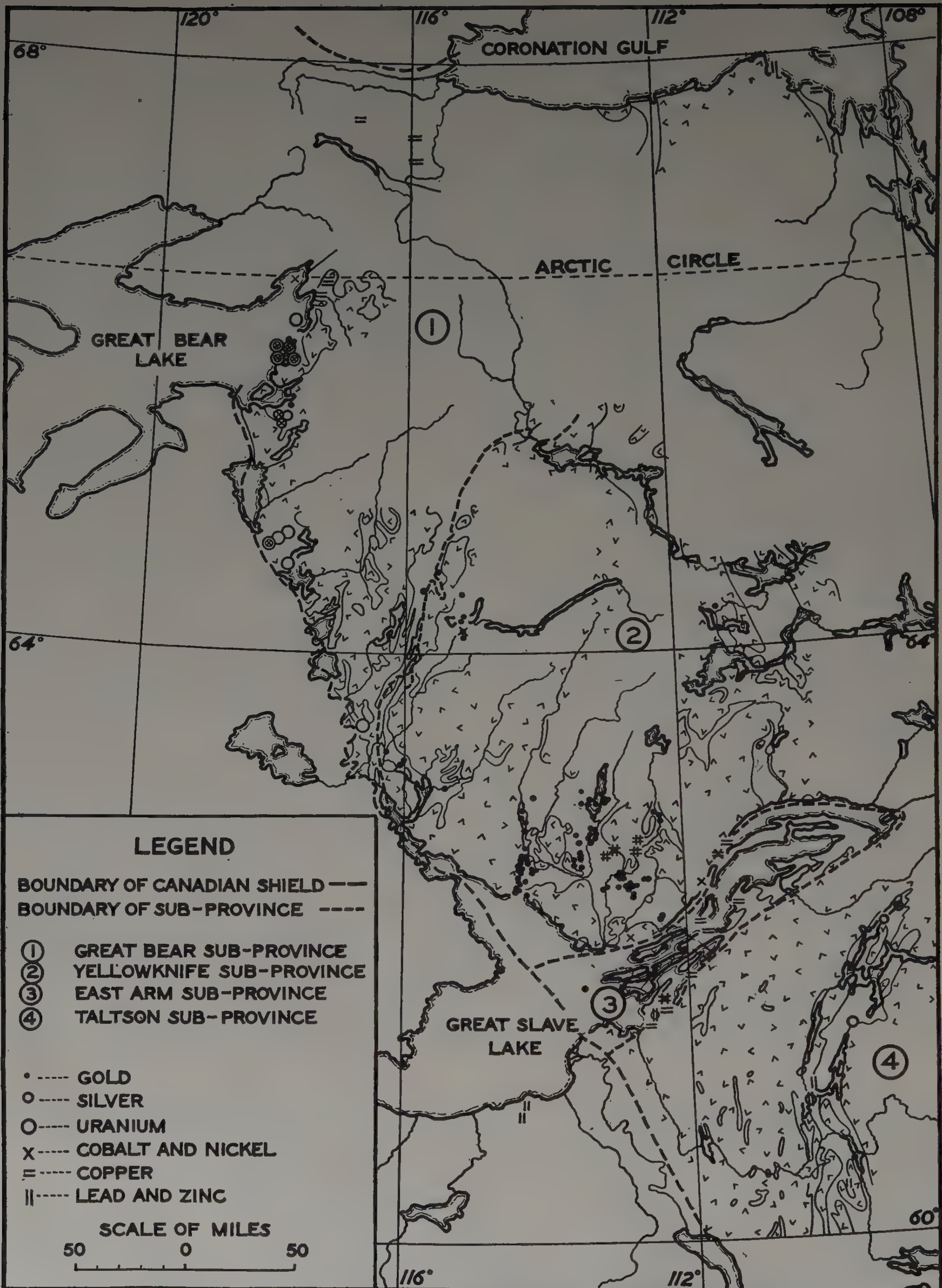

FIG. 3.—*Metal distribution in North-west part of the Canadian Shield.*

south-east (Yellowknife subprovince) having over-ridden that to the north-west (Great Bear subprovince). The East Arm subprovince may likewise be bounded by faults—normal faults on the north and tear faults on the south—resulting in a modified graben structure.

It should be stressed that this division of the north-western part of the Canadian Shield into four subprovinces is based primarily on the geology—on the rock types and sequences—and became obvious early in the compilation of the regional geology. At successively later dates, as the structure unfolded and as prospecting spread throughout the region, it became evident that each geological subprovince is likewise a unit from the standpoint of the nature and distribution of both major faults and certain metallic elements.

So far as the metal distribution is concerned, it might be held that the rather remarkable pattern is coincidental and reflects merely lack of thorough exploration. There is convincing evidence to the contrary. Intensive prospecting around Great Bear Lake started about 1931. To a large extent the prospectors who entered that field were drawn from the gold areas of Ontario and Quebec and, most assuredly, would not consistently pass over any gold-bearing veins. Yet there is record of less than ten gold occurrences within the Great Bear subprovince as against many times that number of discoveries of uranium, a much less common element. Or again, when the Yellowknife field became active a few years later, a goodly proportion of its prospectors came there from Great Bear Lake, skilled in the search for uranium deposits, yet, to the writer's knowledge, not one such occurrence has been found within the Yellowknife subprovince. Even the complex pegmatites there have so far shown no radioactive mineral content.

Furthermore, this concentration of certain metallic elements within limited areas appears to be unrelated to time of formation. In Table I are assembled all available analyses of pitchblende from the Great Bear subprovince that include determination of both lead and uranium content. Only a few of these samples were collected or analyzed specifically for age calculation purposes and, since most of them were taken at or near the surface, modifications in the ratios would be expected due to local selective leaching and deposition—as is evidenced in the field by the erratic distribution of uranium stains. On the contrary, however, the lead-uranium ratios within the limits of each deposit or between obviously related deposits are remarkably consistent. The numerous ratios obtained for Eldorado ores differ only slightly save for a few anomalous values that are doubtless related to near-surface migration of uranium. On the other hand, at the B.E.A.R. mine (only nine miles distant from Eldorado), the one ratio available suggests that the two deposits were formed at vastly different times. The fact that the single analysis of B.E.A.R. pitchblende was specifically for the purpose of an age determination fairly well precludes the possibility that further analyses might close this gap. No possibility whatsoever remains of establishing contemporaneity of deposition of pitchblende at Eldorado and at Beaverlodge and Hottah Lakes, 100 miles to the south. These latter deposits lie along a large quartz vein stockwork that presumably marks a major fault. On the Tatee claims the pitchblende occurs as lenses and disseminations in silicified sediments; on the W.L.O. and W.K. claims four miles distant, it occurs in quartz stringers cutting gabbro. Despite the dissimilar settings, the two deposits are related to the same structure and are presumably of the same age, a deduction that is supported by the general similarity in the lead-uranium ratios, and at the same time may be as much as a thousand million years younger than the Eldorado ores. The implications of these observations are many and varied, only one of which is stressed here: viz. that uranium-bearing hydrothermal solutions were introduced into rocks of the Great Bear subprovince at several periods widely separated in time. On less secure evidence the gold mineralization of the Yellowknife subprovince seems to have been introduced during more than one period. That is, each of these is a separate and distinct metallogenic province. Were chemical analyses available, it is the writer's belief that each of the four areal units would likewise prove to be a petrographic province since, for example, both in the field and under the microscope the igneous rocks from the Great Bear area possess certain textural and compositional features not exhibited by igneous rocks of the Yellowknife area.

TABLE I Lead-Uranium Ratios and Calculated Ages of Pitchblende from Great Bear Subprovince

Location	Pb percentage	U percentage	Ratio	Age in 10^6 years	Reference
Eldorado mine					
surface	(11·13)	(48·3)	0·23		Investigations in Ore Dressing and Metallurgy. *Can. Dept. Mines*, 1930, p. 170. (1934).
surface	(11·27)	(54·2)	0·21		
vein 1 pit 1	7·60	37·14	0·20		Investigations in Ore Dressing and Metallurgy. *Can. Dept. Mines*, 1931, p. 139. (1934).
„ 1 „ 2	5·82	25·73	0·23		
„ 2 „ 7	9·91	43·09	0·23		
„ 2 „ 8	6·46	26·68	0·25		
„ 2 „ 9	13·40	49·19	0·27		
„ 2 „ 10	11·75	52·68	0·22		
„ 2 „ 1	9·22	45·97	0·20		
„ 2 „ 2	11·55	48·21	0·24		
„ 2 „ 3	8·54	46·79	0·18		
„ 2 „ 4	9·67	42·99	0·23		
„ 2 „ 5	2·99	26·14	0·11		
„ 2 „ 6	5·55	38·31	0·14		
20-ton shipment: vein 1 pit 1	7·89	37·82	0·21		Investigations in Ore Dressing and Metallurgy. *Can. Dept. Mines*, 1932, p. 252. (1934).
„ 2 „ 1	8·14	33·92	0·24		
„ 2 „ 2–6	7·23	35·19	0·21		
„ 2 „ 9	10·62	38·96	0·27		
„ 2 „ 9	6·88	27·47	0·25		
	12·35	50·17	0·246		Hecht and Kroupa, *Rep. Comm. Meas. Geol. Time*, p. 60, Sept. (1936).
			0·228[1]		
vein 1 pit 1	10·507	52·316	0·201	1,373	Marble, J.P., *Jour. Amer. Chem. Soc.*, 58, pp. 434-437. (1936).
			0·193[1]	1,323	
			0·180[2]	1,251	Nier, A. O., *Phys. Rev.*, 55, pp. 158, 159. (1939).
			8·88[3]	1,420	
Vein 2, more than 100 feet underground	5·88	29·39	0·200	1,368	Marble, J. P., *Amer. Miner.*, Vol. 22, pp. 564-566 (1937); Vol. 24, pp. 272-273 (1939).
B.E.A.R. mine	2·44	26·31	0·093	623	Hecht and Kroupa, *Rep. Comm. Meas. Geol. Time*, p. 47, April 27 (1935)
Beaverlodge-Hottah Lake					
Tatee 5 claim, 1½ ton shipment (near surface)	2·18	(41·0)	0·053		Haycock, M. H., *Can. Min. Jour.*, 56, pp. 146-147, (1935).
	1·57	(32·6)	0·048		
	2·35	(44·5)	0·053		
	1·05	(18·8)	0·056		
	1·90	(34·9)	0·055		
W.L.O. and W.K. claims (surface)	0·68	11·6	0·059		
	0·52	11·4	0·046		
Tatee 5, Pit 2	2·309	43·63	0·0529	387	Bruner, F. H., *Amer. Miner.*, 21, pp. 265-266, (1936).
	2·492	51·16	0·0486		Baxter and Averill, *Jour. Amer. Chem. Soc.*, 59, pp. 702-705 (1937).
			0·0453[1]	336	
			0·0447[2]	333	Nier, A. O., *Phys. Rev.*, 55, pp. 158-159 (1939).
			5·62[3]	460	

NOTE.—Percentages in brackets are calculated from percentages of U_3O_8 and/or PbO given in the reference. ThO_2 is reported as " nil," " trace," or " less than 0·01 per cent " where tested for. The ages are given as stated in the original works referred to.

[1]=Corrected ratio—obtained by deducting common lead. [2]=RaG/U^{238}. [3]=AcD/RaG.

The conclusion seems warranted that each of these geological subprovinces has persisted from earliest time as a relatively distinct chemical and physical unit—that their characteristic metal associations may reflect heterogeneities present since crustal consolidation, and that, so far as rock sequences and major structures are concerned, the subprovinces have functioned as more or less independent segments each with its own unique geologic history.

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PALEOZOIC NORTH AMERICAN GEOSYNCLINES AND ISLAND ARCS

By MARSHALL KAY

U.S.A.

ABSTRACT

Early Paleozoic North America had a central shield (craton) margined by deeper-sinking belts (miogeosynclines), having carbonates and quartz sands derived from the craton. The traditional "borderlands" of crystalline rocks on the continental margins, Appalachia, Llanoria and Cascadia, are untenable. The continental borders have thick sections, principally of argillites, graywackes, basalt and andesite flows and fragmentals, with some limestones, cherts and conglomerates (eugeosynclines), laid in deep-sinking trenches, adjoining linear volcanic and tectonic islands in paleogeography like modern island arcs. The eastern volcanic belt extends along the Atlantic Coast from central Newfoundland to Georgia, perhaps curving westward into northern Mexico and recurving into the Antillean arc. The western volcanic belt enters southern Alaska, occupies the continental border through south-western California, and is in the extension of modern submarine troughs south of the Aleutians and west of Mexico. Clastics from islands in the eugeosynclinal belts first entered eastern miogeosynclines in mid-Ordovician, western in Carboniferous; they spread into geosynclines (exogeosynclines) within the area of the early Paleozoic craton (hedreocraton) in eastern last Ordovician and western Cretaceous. The craton has elliptical geosynclines isolated from source areas (autogeosynclines) and others deriving detritus from intracratonal uplifts (zeugogeosynclines). Mid-Paleozoic and mid-Mesozoic revolutions consolidated the eastern and western eugeosynclines.

PALEOGEOGRAPHIC maps of Paleozoic North America have commonly shown a central stable nucleus or shield separated by the so-called Cordilleran, Ouachitan and Appalachian geosynclines on the west, south and east from marginal borderlands of granitic and metamorphic rocks, Cascadia, Llanoria and Appalachia. Increasing knowledge, and reconsideration of the assumptions on which the traditional conceptions were based, require that the portrayal be considerably revised (Stille, 1936, 1940; Kay, 1942, 1947; Eardley, 1947; Payne, 1948). The central relatively stable shield or craton developed elliptical and linguiform geosynclines* during spans of time within the era. The Cordilleran, Ouachitan and Appalachian geosynclines of authors are composite geosynclines of several sorts formed through varying times. Areas that have been considered as borderlands are sites of major geosynclines associated with volcanic and tectonic islands, the whole consolidated into greater lands by orogenies within and subsequent to the Paleozoic.

A paleogeographic map for the early Ordovician illustrates the elements of the Paleozoic continent (Fig. 1). Early Cambrian geography was similar except in lacking the interior coastal plains. Seas covered much of the interior in most Paleozoic times. The central region or craton, land on the selected map, was relatively stable through much of the earlier Paleozoic, whereas belts on the west, south and east were dominated by sinking. This interior, the hedreocraton, was separated by flexures from thick miogeosynclines composed of quartz sandstones (silicarenites) gained from the hedreocraton, and carbonatites (calcitites and dolomitites) in the Millard and Champlain belts.

Belts more distant from the hedreocraton contrast in the prominence of volcanic rocks and are thus eugeosynclinal, as recognized by Stille (1936, 1940); whereas there are miles of lavas and fragmental volcanics in many systems in widely distributed parts of the Fraser and Magog belts (see Fig. 1), very few are known in the miogeosynclinal belts, and only a single flow in the Devonian of Ontario

* Geosyncline is applied to rocks having thousands of feet thickness over considerable area. Earlier papers (Kay, 1947; Glaessner and Teichert, 1947) summarize the terminology of geosynclinal classification.

on the hedreocraton. The volcanic-bearing eugeosynclines have additional argillites and graywackes in greatest frequency, calcitites, cherts and conglomerates locally prevalent; quartzites (that is quartz arenites, not metacherts) and dolomitites are rare.

Volcanic rocks are quite varied. Quantitative information is inadequate, but descriptions of lavas and coarser fragmental volcanics in about 100 Paleozoic sequences show basaltic and andesitic lavas to be of similar quantities, more frequent than rhyolites, which are locally thick and prevalent, however. Many of the lavas are interpreted as submarine flows, but agglomerates and conglomerates of volcanic cobbles indicate volcanic islands. There were also tectonic islands, for unconformities bevel sediments and intrusions into sediments within the Paleozoic, and there are thick conglomerates having plutonic and sedimentary rock pebbles; though some of these latter fragments may have been projected by

FIG. 1.—*Paleogeographic Map of North America in Ordovician times.*

volcanism, their local abundance shows that some came from the erosion of plutonic and sedimentary terranes. Finally, detrital sediments from sources in the eugeosynclinal belts were carried into miogeosynclinal belts as shown by direction of coarsening, first in the Ordovician in the East, and in the Carboniferous in the West. The writer has prepared maps summarizing the data on age, distribution and composition of volcanic rocks on the Atlantic and Pacific coasts and on age and distribution of unconformities on Paleozoic sediments and intrusions and of plutonic pebbles in conglomerates.

Thus, early Paleozoic North America had a relatively stable central shield or craton, the hedreocraton, margined by non-volcanic miogeosynclines, and more distant volcanic and sediment-bearing eugeosynclines with volcanic and tectonic islands. The last were ancient island arcs like the present East and West Indies. Their very geography is suggestively similar, with the festoons of volcanoes. Serpentines and ultrabasic intrusions are restricted to them just as they are characteristically along present arcs (Hess, 1939). The oceanic troughs in the Pacific south of the Aleutians and west of Central Mexico trend toward the Paleozoic eugeosynclinal rocks in the Fraser belt; mid-Mesozoic orogenies with accompanying intrusions destroyed the island geography and consolidated the areas into the continent. The distribution of Paleozoic volcanic rocks suggests that the Fraser eugeosynclinal belt entered from the Aleutians and passed via the Pacific off Mexico to the western Andes and that the Magog eugeosynclinal belt on the Atlantic Coast curved westward into northern Mexico and south-eastward into the extension of the present Antillean arc about north-eastern Guatemala (the trend of volcanic islands in Fig. 1 should lie within the eastern Mexican coast).

The eugeosynclinal belts of North America gained the principal plutonic intrusions, an exception being the entrance of the Boulder Batholith of Idaho and Montana into the miogeosynclinal Millard belt. They were the sites of major orogenies particularly the middle Mesozoic Nevadian in the West and the post-Ordovician Taconian in the East; the Waramian and Appalachian orogenies principally affected the miogeosynclinal Millard and Champlain belts and the borders of the hedreocraton.

The eugeosynclinal belts of North America have Paleozoic rocks and histories very like those of the pre-Caledonian Paleozoic areas of Wales, north-west England and south-west Scotland. Such histories have temporal limits. The pre-Paleozoic or Proterozoic geography of North America had quite different patterns; at one time eugeosynclines extended north of the Great Lakes from western Ontario into Quebec just as there are Proterozoic eugeosynclinal belts in the midst of the European Paleozoic Fennoscandian craton.

The principal geosynclines in North America in the Paleozoic, the miogeosynclines and eugeosynclines, are outside the hedreocraton, but there are other geosynclines within the hedreocraton. When parts of the Magog Belt rose in the late Ordovician, terrigenous sediments were carried westward into a semilenticular geosyncline lying partly within the hedreocraton in Pennsylvania and nearby areas (Kay, 1942). These types of geosynclines, lying within a craton but gaining sediment from land raised in geosynclinal belts outside the craton, are exogeosynclines. The late Ordovician sediments coarsen upward and outward as the source continually or interruptedly rose more rapidly than it was denuded; deposits of this sort have been classed as flysch by some geologists, though this usage has been criticized (Eardley and White, 1947). The early Silurian in the same region is a molasse exogeosyncline, the detritus becoming finer upward. Another flysch exogeosyncline in the same region is of Middle and Upper Devonian age; it was to the source of this delta that the name Appalachia was originally applied.

A second type of geosyncline within the hedreocraton is exemplified by the late Silurian of Michigan, non-terrigenous carbonatites and saline rocks approaching a mile maximum in the centre of Lower Michigan, thinning to only a fraction toward the margins of the state. This is an autogeosyncline, one lying within the craton, isolated from any great uplift. The third type of intracratonal geosyncline, the zeugogeosyncline, is represented in the late Carboniferous of Colorado and New Mexico; thickness of as much as two miles of detritus formed in deeply sinking parts of the hedreocraton in complement to geanticlines raised within the hedreocraton. Each of these types is represented by several examples in the North American hedreocraton. They tend to be rather evanescent, recording sinking in a part

of the continent for a period or two, followed by lapse of deformation or warping of a different pattern.

The eastern eugeosynclinal or Magog belt was strongly deformed and invaded by plutonic intrusions in the Shickshockian orogeny within the late Devonian. Subsequently, geosynclines of the Carboniferous rocks of the Maritime province of Canada reached a few miles thickness, laid in relatively narrow tectonic troughs separated by rising lands; volcanic rocks are relatively infrequent and the geosynclines have been termed epieugeosynclines. Comparable orogeny and plutonic intrusion affected the Fraser belt in mid-Mesozoic, though there were earlier intra-Paleozoic orogenies and intrusive epochs of lesser magnitude.

Thus the North American Paleozoic had geosynclines of several sorts within the hedreocraton and bordering miogeosynclines and eugeosynclines with associated volcanic and tectonic island arcs. The latter were altered by mid-Paleozoic orogenies in the East. The Paleozoic geosynclines had quite different distribution than those of the Protozoic. They directed considerably the structure and form of the present North American continent.

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SEDIMENTATION PHENOMENA OF THE CRETACEOUS OF THE BLACK SEA REGION BETWEEN ZONGULDAK AND EREĞLI, ASIA MINOR*

By W. J. McCALLIEN and MELIH TOKAY

Gold Coast and Turkey

ABSTRACT

The Black Sea coast of Turkey between Zonguldak and Ereğli is best-known for its coal-bearing Carboniferous sediments. These occur as inliers in a great thickness of Cretaceous limestones, sandstones, shales, tuffs, etc. Because of the economic importance of the region, therefore, the Cretaceous has been studied by many geologists mainly concerned with Carboniferous studies. It has long been known that the Cretaceous sediments are of great interest because they contain great exotic blocks (" klippes ") of Carboniferous material. Some of the blocks are so large that the coal seams in them have in the past been exploited. P. Arni attributed the origin of the blocks to a combination of sedimentation and tectonic phenomena. The present authors extend and amplify Arni's studies to show that the boulder beds are accompanied by the usual phenomena of submarine slumping due to earthquake movement.

INTRODUCTION

THE present study deals with the coastal belt of Anatolia bordering the Black Sea between Zonguldak and Ereğli (Fig. 1). The region is well known because it contains the Turkish Carboniferous coalfields, and for this reason it has been studied longer, and in greater detail, than most parts of Anatolia. Although previous investigators were primarily concerned with the Carboniferous, several

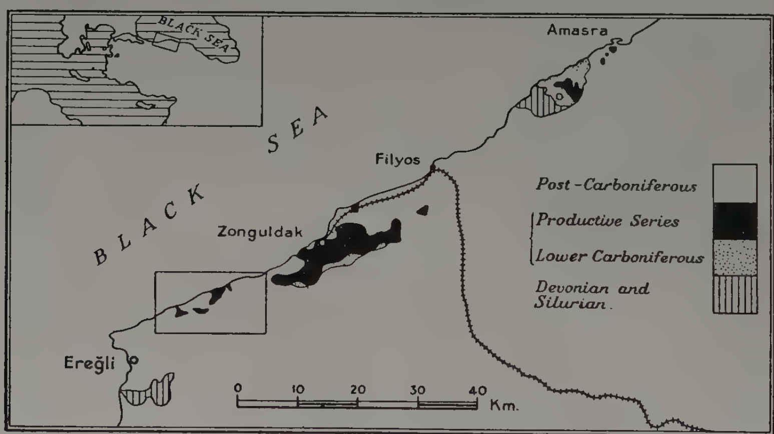

FIG. 1.—*Index map of part of the Black Sea coast of Asia Minor.*

made important studies of the overlying Cretaceous, because the two are closely linked together in the field. Among these investigators P. Arni has made the most important contribution to our knowledge of the areal distribution of the Cretaceous and of its sedimentation phenomena. Arni's maps and descriptions have been the guides and inspiration of our own work. Later, we shall refer in some detail to Arni's views. Here, let us say that our revision of the subject has made us realize the great advances which Arni made in the interpretation of slumped submarine sediments at a time when geologists in other parts were just beginning to see the true nature of the problems involved.

* The writers wish to thank the Director of the Geological Survey of Turkey for facilities for study in the field and for permission to publish this paper. Professor McCallien also wishes to thank the Royal Society of London for financial aid for studies in Anatolia.

Our opportunities for study can be summarized as follows. One of us (W. J. McC.) came to Turkey in 1944 and at the first opportunity, in 1945, visited the region to see the phenomena of "blocks and klippes" described by Arni. The other author (M.T.) was at the same time given the task of revising the Cretaceous on behalf of the Geological Survey of Turkey in the general plan for the revision of the coalfields. Independently we came to the same general conclusions regarding the slumping, and since then we have visited many of the sections together.

While our ideas were developing, and while Melih Tokay continued with the mapping, F. Charles was also working on behalf of the Geological Survey in adjacent regions on both the Carboniferous inliers and their Cretaceous cover. He came to conclusions diametrically opposed to our own and saw in many of the sections evidences of great tectonic overthrusts. In view of these differences of opinion we consider it necessary to reconsider the evidence for submarine slumping first put forward by Arni and to bring the story of the Black Sea boulder beds into line with the other great boulder beds of the world.

PHYSICAL FEATURES

In general the coastal strip between Zonguldak and Ereğli runs in a S.S.W.-N.N.E. direction without any important deviations from the straight. The coast is precipitous and the cliffs of the north-eastern half of the stretch are interrupted only by a few small beaches where the more important valleys reach the sea. Usually, the high ground near the coast of this part is well forested down to near sea level. Access from the sea is possible and often affords the best approach to certain regions. The limestone-cliff stretch extends as far south-west as Çamli and Köseagzi. To the south-west of this there are high cliffs of tuffs and agglomerates with occasional large bays, and gradually the heights of the cliffs decrease towards Ereğli. At Ereğli, the coastline suddenly cuts southward for some twenty kilometres across the general strike of the rocks and makes access to the hinterland easy in this direction.

Inland from the coast, the area studied is a highly dissected series of peneplains with steep slopes and deep young valleys. The slopes and valleys are often forested, but long cutting of the trees has given a patchy distribution of woods and fields over the whole hinterland. In the course of the past two years a motor road has been made by the Geological Survey (M.T.A.E.) from Kozlu to the south-west as far as the approaches to Neyrenköy. In addition to furnishing easy access to this region, the new road has given many additional sections and, in several places, these disclose interesting sedimentary structures.

STRATIGRAPHY

(*a*) *Carboniferous*

In the present paper we are specially concerned with the sedimentary structures of the Cretaceous south-west of Zonguldak, but because of the nature of some of these sediments, and of the problems involved, it is necessary to discuss briefly the nature and distribution of the Carboniferous and older rocks.

So far as we know, the oldest rocks of this part of Anatolia are represented by the Silurian shales recently discovered by Egemen at Yarasliköy on the Guluç River just south of our region. Previous to the discovery of Silurian graptolites these older rocks have been grouped together as Devonian, and Egemen still accepts the greater part of the inlier as of this age. The existence of the Devonian in this southern belt is of importance in our present study. The actual Carboniferous outcrops, in the region under consideration, lie in the northern coastal belt, but it is generally admitted that the limestone facies of the Devonian probably continues upward into the Carboniferous and there may, therefore, be a hidden southern belt of Carboniferous. Far to the north-east of the Zonguldak-Amasra coalfield region, a southern Carboniferous belt is partly exposed in the Kure Mountains, south-west of Inebolu, and it is not unnatural to expect this to continue to the south-west as far as

our own region. Later, we shall have occasion to postulate the existence of exposed Carboniferous during the Cretaceous in this very region.

The largest outcrops of Carboniferous occur between Zonguldak and Kozlu just outside our region to the north-east. To the south-west, however, there are several important inliers which suggest that the Carboniferous is probably continuous beneath its Cretaceous cover. Beginning in the north-west, the most important of these inliers occur at Iliksu, Çatakdere, Kireçlik-Kirenlik, Teflenli, Alacaağzi, Armutçuk, and Çamli-Neyrendere.

The Carboniferous is subdivided as follows:

Karadon series
Kozlu series
Kiliç series
Alacaağzi series
Viséan limestones

The local divisions can be correlated with the better known Carboniferous divisions (Heerlen, 1927) as follows:

Karadon ....Westphalian B,C,D.
Kozlu and upper Kiliç ....Westphalian A.
Alacaağzi and lower Kiliç......................Namurian A,B,C.

On the whole the Alacaağzi series consists of sandstones, shales, and conglomerates with a few fossiliferous marine beds. The Kozlu series consists essentially of sandstones and conglomerates in beds of considerable thickness. The Karadon begins with thick conglomerates and later becomes sandy.

In a few places, as for example, in the neighbourhood of Kozlu, a thick series of red (and green) sandstones lies between the Carboniferous and the basal Cretaceous conglomerate. In the absence of fossils the age of these beds is difficult to determine. Nevertheless, they represent the products of a period of emergence which succeeded the main folding of the Carboniferous.

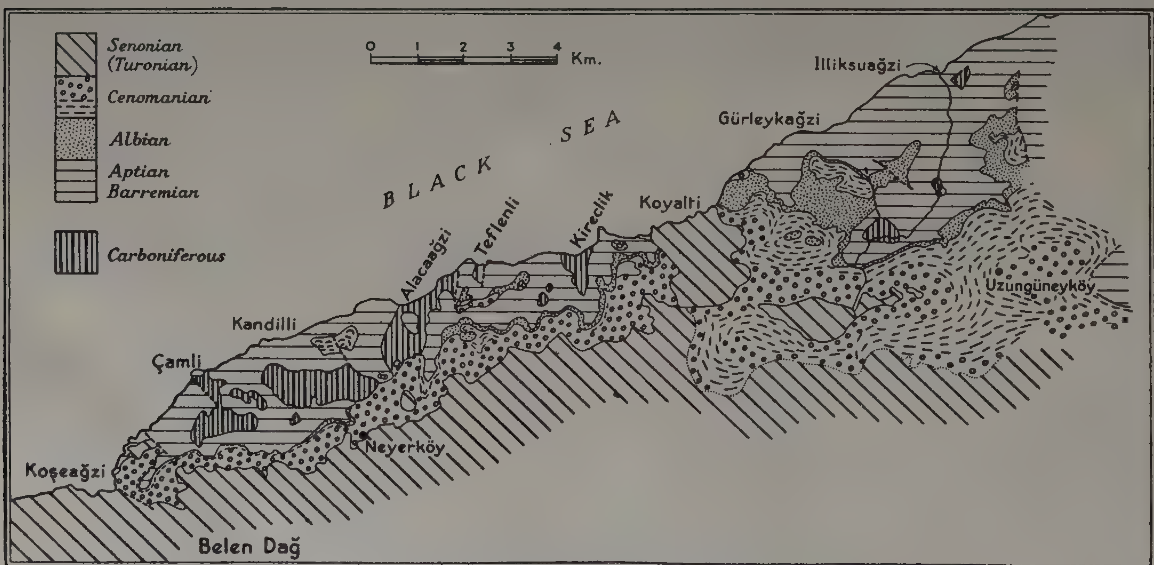

FIG. 2.—*Geological sketch map of the Black Sea coast south-west of Zonguldak (after Arni). (For Neyerköy read Neyrenköy)*

(*b*) *Cretaceous*

Details of the Cretaceous rocks have been given by Arni. Here we shall merely summarize the main characteristics. The Lower Cretaceous begins with a Basal Conglomerate consisting of boulders and pebbles of Dinantian limestones and cherts with less frequent Carboniferous sandstones. The thickness of the Basal Conglomerate varies from place to place, but it is usually very conspicuous.

According to Arni the Basal Conglomerate is of Barremian age. Earlier geologists like Ralli, Lebling and Amsler, believed that it was older than the Cretaceous. Charles has attempted to show that the age of the conglomerate varies in different places, older than the Valanginian in some and immediately pre-Barremian in others.

Lower Schrattenkalk.—The Basal Conglomerate is usually overlain by a considerable thickness of massive limestone called the Lower Schrattenkalk by Arni and we may retain this name. The limestone is attributed to the Barremian by this author, but a recent find by Egemen of *Berriasella* sp. at Teflenli suggests that, there at least, the lower limestone may be somewhat older, perhaps Valanginian.

Incüvez Shales.—A series of marls and shales characterized by very abundant *Orbitolina lenticularis* Blum. (d'Orb.) and of Lower Aptian age.

Upper Schrattenkalk.—Similar to the Lower Schrattenkalk. The Upper Schrattenkalk passes laterally and vertically into the *Velibey Sandstone.* It is generally believed that the Velibey Sandstone is the southern facies and the Upper Schrattenkalk the northern facies of the Upper Aptian. The Velibey Sandstone, which is normally non-calcareous, is characterized by the presence of small rounded quartz pebbles more or less irregularly scattered through the sandstone. In places it is somewhat conglomeratic, but the sandstone with the isolated quartzes is conspicuous in the field.

Albian Sandstones.—These are for the most part glauconitic calcareous sandstones and sandy limestones overlying the Velibey Sandstone and well known as furnishing a good fossiliferous horizon. In our region the glauconitic sandstones are often conglomeratic. They are overlain by blue marls and shales of which it is possible that the lower part belongs to the Albian.

Cenomanian.—The marls and shales mentioned in the last paragraph probably belong in their upper part to the lower Cenomanian. The upper Cenomanian consists of a mixed assemblage of marls, shales, sandstones, limestones, and boulder beds. The boulder beds often contain very large blocks of lower Cretaceous limestones and Carboniferous materials. They vary in size up to some hundreds of thousands of cubic metres. The boulder beds contain fragments of practically all the older rocks: Dinantian, Namurian, Westphalian, Cretaceous Basal Conglomerate, Cretaceous limestones, Velibey Sandstone, and Albian sandstones.

The Upper Cretaceous (Turonian-Senonian) is transgressive on the older rocks and in its lower part consists of a thick series of tuffs, marls, sandstones, etc. Overlying these are andesites, marly limestones, tuffs, sandstones, and chalky limestones.

THE CRETACEOUS BOULDER BEDS

As we have already pointed out, the Cenomanian boulder beds are characterized by the presence of blocks of great size. The most detailed and enlightened study of these boulder beds was made by Arni, according to whom they occur sometimes at the summit of the Cenomanian flysch beneath the Upper Cretaceous and in general characterize the flysch a short time before the end of the Cenomanian. Particularly large blocks have been noted by Ralli and Arni at Seyfetler, Uzungüney köy, Çavusağzi, and Koseağzi. The dimensions are sometimes those of a house, and one block was measured as 600-700 m. long by at least 50 m. where it was cut through by the Çavus stream, and 300-400 m. from east to west. Not unnaturally, Ralli looked upon this as an outcrop of autochthonous Carboniferous.

Arni drew attention to the complex sedimentary structures visible in the flysch beneath these great boulders and concluded that these structures had been caused by the sliding of the blocks themselves into the Cenomanian sea. With this view the present authors are in complete agreement.

Until now some three theories have been put forward to explain the origin of the boulder beds. Amsler believed that active tectonic folding of the Carboniferous into the Cretaceous was directly responsible for the phenomena. The folding and involution took place in the sea to the north of the present outcrops. According to Amsler the folds which were produced were beheaded by erosion and thus were formed the boulder beds. Arni agrees to the existence of a tectonic line of the greatest importance to provide the blocks but attributes this to breaking without folding along the line of the present Belen Dağ to the south of the region. As the result of this breaking the fragments were suddenly overturned towards the north into the Cenomanian sea. Later, the view has been expressed by Charles that the " blocs exotiques " of Arni must be considered as " lames tectoniques." Paréjas saw in the boulder beds a relation between sedimentation and the Austrian phase of alpine folding. He wrote that the great blocks " pourraient représenter . . . des lambeaux tectoniques . . . leur présence dans le Flysch cénomânien indique que le paroxysme austrique a été particulièrement violent dans les bassins houillers de l'Anatolie du nord. Cette violence localisée se serait traduite dans un cas par la formation de reliefs élevés qui auraient subi une érosion très active soulignée par des éboulements de nappes et de klippes . . ."

The phenomena of submarine slumping and submarine earthquakes are now well known. In the northern zone of Anatolia we have recognized many of the phenomena in the sediments of both the lower and upper Cretaceous. In the present paper we offer a few illustrations of the sedimentary structures which in our opinion support the view that the Cenomanian boulder beds, as well as the older and younger sediments of the Cretaceous, were deposited during a long period of tectonic unrest accompanied by earthquakes and their associated submarine waves. The line of origin of the earthquakes is now difficult to locate but we believe that Arni was near the truth when he suggested somewhere to the south, in the region of Belen Dağ.

Great exotic blocks in the flysch of the European Alps have long excited interest. Long ago Schardt put forward the view that the great boulder beds were formed as landslips from tectonic scarps, although later he modified this conception to bring it into line with the theory of the formation of the Pre-alpine klippes. In 1928, Bailey, Collet, and Field put forward the submarine landslip theory to explain the Quebec boulder beds. These are of Ordovician age and were explained as having been formed by slipping down a fault scarp. The slipping was caused by earthquakes accompanying the formation of the fault. In this case the boulders are of much the same age as the shales in which they are embedded, but like those of the Alps they are exotic, for the Quebec boulders are of the shallow-water facies of which the shales are the deep-water equivalents. Much of the evidence from Quebec applies also to Anatolia, although here the boulders are often of older rocks than the matrix. In both cases the boulder beds are of submarine origin because they are embedded in marine shales or sandstones. They are associated with a particular belt and, as previous writers have emphasized, their internal arrangement is most irregular. Arni was the first to suggest that some of the boulders seem actually to have ploughed into the matrix, part of which became injected along cracks and faults.

In their paper on the Quebec boulder beds Bailey, Collet, and Field suggested that the theory of submarine slipping would account also for certain Jurassic boulder beds along the coast of East Sutherland in Scotland. In 1930 and the following year Bailey and Weir were able to make a detailed investigation of the Sutherland beds and their description of the district marks one of the landmarks in the interpretation of submarine slumping. Since that time Bailey has done much to encourage the investigation of sedimentary structures, both as a means of interpreting complex fold-mountain structures, and as a method of unravelling the history of the sediments themselves.

We cannot discuss the other examples which have been described but we may summarize here the characteristic features of slipping due to submarine earthquakes which have been found both in Anatolia and in other regions such as Quebec and Sutherland. Among the features are the following: the inconstancy and sudden variations in thickness of the boulder beds; the intercalated nature of the boulder beds in the marine sequence; the large size of many of the blocks; the folding and disturbance

of the underlying shales; the injection of sand and mud into the beds; the preservation of angular and highly irregular fragments of shale and sandstone in a matrix of either mud or sand. Among some Anatolian boulder beds, as in other regions, there is also a grading from large fragments at the base to fine material at the top. In addition, there are many instances of current deformation of the beds producing anti-dune structures like those described by Lamont.

Angular and irregular fragments of shale in sandstone or grit have been figured by many writers. The fragments are obviously not water-worn and they have often long delicate projections into the matrix. They are pictured as having been formed by seismic shakes which both broke up the sediment and caused a sudden incursion of the material now forming the matrix (Fig. 3).

As regards the type of ripple marks spoken of as anti-dune, Lamont has emphasized the fact that they indicate the existence of bottom currents of considerable swiftness. Anti-dune ripple marks have been seen in the Cenomanian of northern Anatolia. These curious structures were preserved by their sudden envelopment in a later sediment, usually sand.

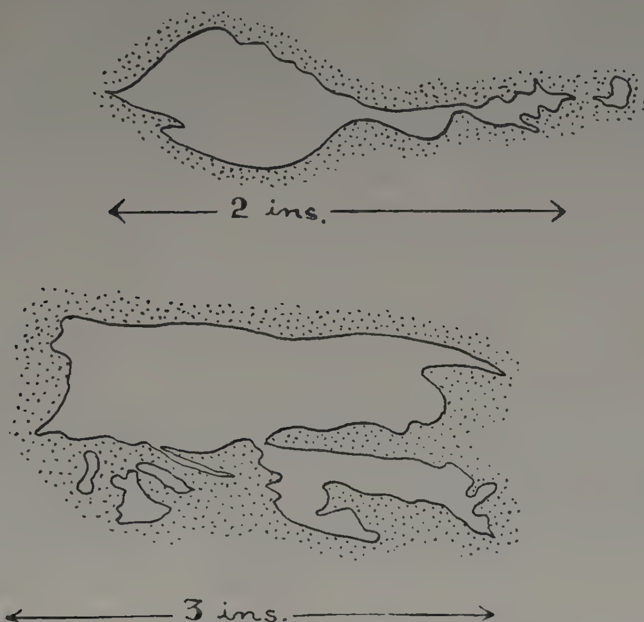

FIG. 3.—*Shale fragments in grit. Uzungüney valley, near the mill, W.S.W. of Uzungüney village. Upper Cenomanian.*

The sedimentary structures referred to here have been observed in various places from Albian times onward. In previous works submarine slipping phenomena have been thought to be restricted to the Upper Cenomanian and to the horizons of large boulders in particular. Boulder beds of Albian age, consisting of penecontemporaneous sandstone boulders in glauconitic calcareous sandstones, have been seen in the valley of the Havurtlak river, north-east of Uzungüney village. Just above the confluence of the Havurtlak and Gökgöl, a valley entering from the east, there are excellent exposures of Albian limestones, sandy limestones, fossiliferous glauconitic sandstones, and boulder beds at, and immediately below, the ford on the road leading to Yuvarta village. Both boulders and matrix of the boulder beds contain glauconite, but the sand grains in the boulders and pebbles are larger than those in the matrix. This is taken to indicate the derivation of the boulders and pebbles from a contemporaneous shallower water facies than the matrix. Beds of the same age as these are exposed on the

coast north-east of Zonguldak, at Kilimli. There, the boulder beds form a spectacular outcrop, but as the region is beyond our present district we shall not describe it here.

It is interesting to point out that the boulder beds referred to above in the Havurtlak valley have been interpreted in the past by others as evidence of a great transgression. Here we prefer to look upon them as early episodes in the great earthquake story.

The above rocks rest on the Velibey Sandstone which, we have already said, is a sandstone with many dispersed quartz pebbles. Although we have not studied this horizon from the point of view of submarine earthquakes it appears to us that it represents a rather peculiar type of sedimentation which may in some way be connected with submarine earthquakes. That is a subject for future investigation.

Together we have examined the Cenomanian boulder beds in the regions of Neyren village and Uzungüney village, and separately we have studied them in other parts. One of the most striking features of the Neyren district and of Uzungüney is that practically the whole upper Cenomanian is characterized by repetitions of boulder beds. Sometimes they are comparatively thin and relatively inconspicuous, but they point, without doubt, to the repetition of the tectonic disturbances which, until now, have been associated by others only with beds containing the large blocks.

One of the most interesting sections of the Cenomanian in the Neyren village neighbourhood occurs on the road to Armutçuk just below the conspicuous hill on the outskirts of Neyren. There, the road passes through a small gulley with sections of folded rocks on either side. Before reaching the folded sediments one sees a great block of limestone apparently resting on the shales and sandstones. The shales and sandstones, in beds of from five to forty centimetres in thickness, show the most remarkable slump-foldings. In a distance of some ten metres one sees the shales and sandstones horizontal or folded into overfolds and thrusts of the most complex nature. The direction of movement is difficult to determine for sometimes it is to the south and sometimes to the north. In other parts all signs of stratification have been destroyed.

The highly folded and disturbed shales and sandstones are similar to the beds, which a short distance above, remain horizontal or almost horizontal. There is little doubt that the disturbed beds, the boulder beds, and the great limestone blocks of this road section are restricted to a horizon interstratified among the undisturbed strata above and below.

At Uzungüney village and in Uzungüney valley the evidences of submarine slipping accompanied by submarine earthquake phenomena are striking, although in the past year other interpretations have been given to the structures. The phenomena of blocks are particularly well seen on the hill to the east of the village of Uzungüney and on the slope across from the village. This region has been referred to in considerable detail by Arni, but we have identified additional structures in support of his view of submarine slipping. In the Kizilca Kese district, to the north-east of Uzungüney, the Cenomanian is represented by a considerable thickness of blue shales and marls. These are overlain by thin boulder beds, current-bedded and slip-bedded sandy limestones, and sandstones with coaly fragments, coaly lenticles, and beds of broken up coals. The lowest boulder beds occur in the stream already referred to in connection with the Albian conglomerates near an old mill, and again on the lower slopes of Çamci tepe.

The phenomena of the Uzungüney district consist of many familiar structures besides the folding associated with the great blocks. Here we shall refer only to some of them illustrated from the Uzungüney valley a short distance north of the confluence with the Aşağiçayir entering from the east.

Fig. 3 shows two of the many fragments of shale in a sandstone or gritty matrix, and they immediately recall the illustrations of similar fragments from other regions of submarine slumping. As we have already said, such breccias are interpreted as having been formed by the sudden breaking up of the shaly material and the equally sudden engulfing of the broken material by grit.

Fig. 4 shows a thick sandstone injection into blue marls.

Fig. 5 shows the casts of anti-dune ripple marks in sandstone. The ripples were formed on the underlying shales and marls which have now been eroded from beneath the hard grit bed. The latter also contains lenses and irregular fragments of the shales.

We shall not refer to the folding of the sediments of this region because throughout the length of the boulder-bed horizons complex folding overlain by unfolded strata are the order of the day. Reference must be made however to the fact that some of the foldings have recently been described by Charles as *plis couchés* in support of his theory of great overthrustings in the Cretaceous of this part.

Upper Cretaceous

Turonian-Coniacian.—Beds of this age are well exposed in many places, particularly along the new road referred to in the introduction. Coastal sections are also abundant from Koseağzi to the west. The rocks are essentially well-bedded tuffs, marls, limestones and agglomerates.

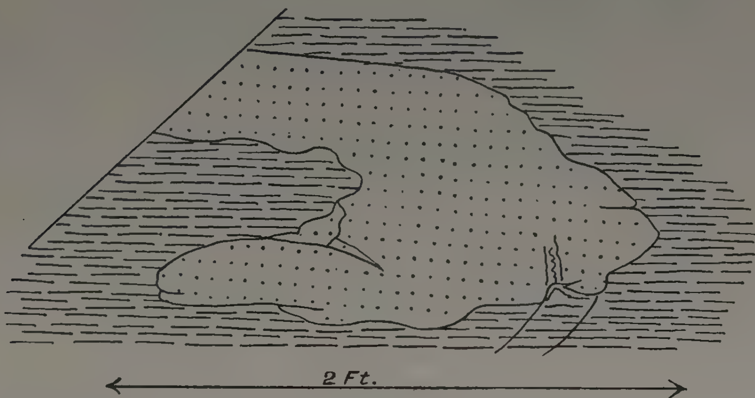

FIG. 4.—*Sandstone injection in shales and marls. Near the mill, Uzungüney valley, W.S.W. of Uzungüney village.*

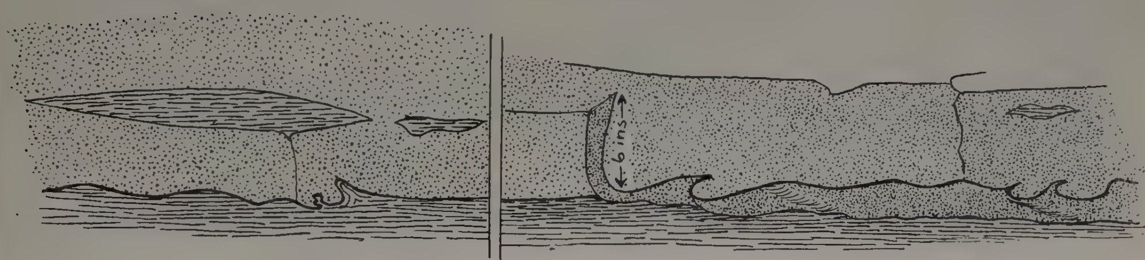

FIG. 5.—*Anti-dune ripple crests cast in sandstone overlying shales. Uzungüney valley, W.S.W. of the village of Uzungüney.*

With the end of the Cenomanian the phenomena of great boulder beds seem to have ceased, but, in at least one place, the marls of the Upper Cretaceous are folded and overthrust in a manner just as complicated as the foldings below the great blocks. We refer here to a new section on the M.T.A. road in the upper part of the valley of Alacaağzi where Fig. 7 was sketched.

Graded bedding is the characteristic feature of the Upper Cretaceous. Graded bedding can be seen in almost every section of the new road from Dagköy to Neyren village and again in the coastal sections at Koseağzi. The graded beds are here described as tuffs and agglomerates but it must be emphasized that they are marine sediments. It will be recalled that graded bedding is characteristic of many geosynclinal sediments, and Bailey has suggested that submarine earthquakes acted as the distributing agent of mixed sediments into the waters of the geosyncline beyond the reach of ordinary currents. This view is in close agreement with our own on the origin of the graded bedding and associated folding of the marls and shales of the Upper Cretaceous. It will be noticed from Fig. 6, which may be considered typical of the sedimentary features of the whole sequence, that the graded beds are usually separated

from one another by a few inches of well bedded shales. The latter are sometimes evenly bedded, but in most cases there is evidence somewhere along their course of sedimentary contortions. Moreover, the upper surface of the shales was usually violently eroded after the folding and before the deposition of the coarser basal portion of the overlying graded bed. The field evidence, therefore, seems to suggest the existence of two types of quiet-water sediment. The normal sediment is represented by the shales and marls. During their deposition, however, submarine disturbances caused slipping and folding on

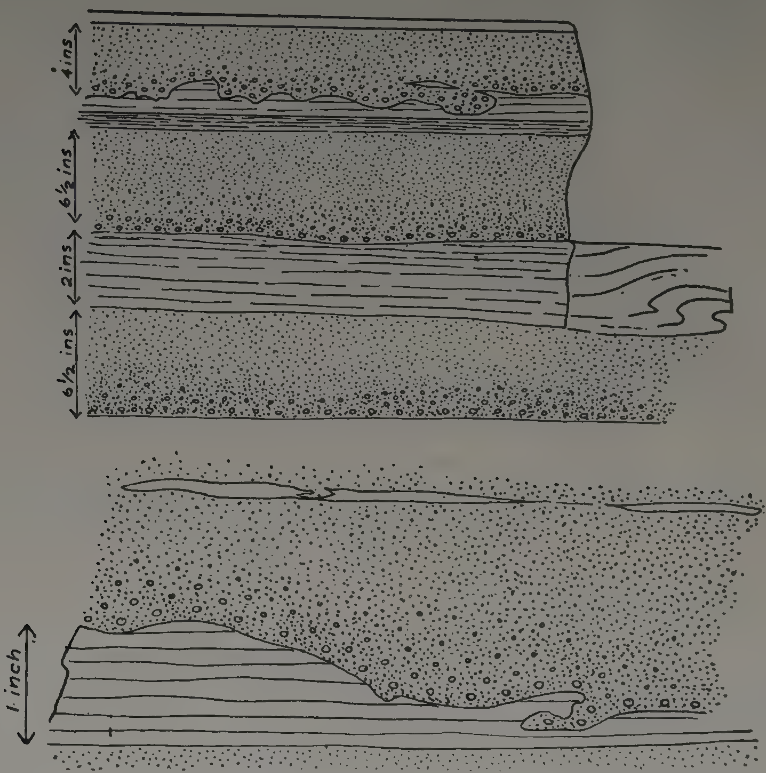

FIG. 6.—*Graded-bedded Turonian-Coniacian sediments on the new road from Dagköy to Alacaağzi.*

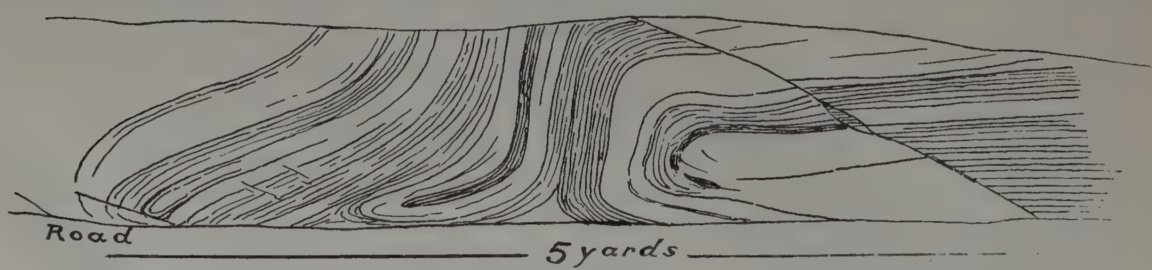

FIG. 7.—*Sedimentary folding in Coniacian marls, roadside, new road to Alacaağzi.*

the sea floor. Each submarine disturbance caused a violent submarine wave responsible for the erosion of the upper surface of the shales and at the same time responsible for the introduction into the region of the mixed sediments of coarser material which then settled quietly as the graded-bedded beds.

The type of bedding described above is characteristic of a large area and our present investigations have not extended into the region to the south of it.

Fig. 7 illustrates the complex folding on the new road to Alacaağzi.

PALAEOGEOGRAPHY AND CONCLUSION

Arni, Charles, Paréjas and others have contributed to our knowledge of the palaeogeography of the Pontic mountain belt at present under discussion. In view of our own conclusions it can be said that the Black Sea coastal region, from Ereğli to Zonguldak and beyond to the north-east for at least 200 kms., was an unstable region throughout practically the whole of the Cretaceous.

The axial elevations of the Pontic mountains which now bring the Carboniferous rocks to the surface are separated by depressions of which the most important is that of the lower Filyos valley, north-east of Zonguldak, where the Upper Cretaceous now reaches the sea in a long coastal strip. Paréjas has already discussed the importance of this depression during the Mesozoic.

Before Cretaceous times the western part of Pontic mountains referred to above was deeply eroded, and today the Lower Cretaceous rests directly on the Carboniferous. To the north-east and east, Permian, Trias, and Jurassic rest on the older Palaeozoics, including Carboniferous.

With the beginning of the Cretaceous, the coastal belt of Carboniferous inliers east and west of Zonguldak was submerged, whereas the country to the south remained above the sea. The Upper Cretaceous transgression brought the sea far to the south and today the Upper Cretaceous there rests on the Devonian and Silurian.

The Lower Cretaceous of the coastal belt apparently thins towards the south and all the evidence suggests that the sea was open to the north. We agree with Arni in believing in the existence of an irregularly eroded surface of folded Carboniferous at the beginning of the Cretaceous. This is brought out by the variable thicknesses of the accumulations of the Basal Conglomerate. In Barremian-Aptian times the reef limestones were succeeded by a marly facies (Bedoulian) which was followed by the deposition of further reef limestones. These are interbedded with sands towards the south and in this direction the Velibey Sandstone becomes important. The Albian glauconitic sandstones show evidence of tectonic disturbances in their boulder-beds and from this time to the end of the Cenomanian the sediments are mainly alternations of blue shales and boulder-beds. The latter are of great importance in the Upper Cenomanian. The evidence of the boulder-beds suggests the repetition of great fault movement due to earthquakes. As a result, blocks and rubble of pre-Cenomanian rocks were suddenly discharged into the seas with accompanying folding and disruption of the normal shaly sediments. This phase continued for a long time and was followed by the complete subsidence of the whole area after the end of the Cenomanian. During the Turonian-Coniacian, volcanic activity became important. In the region actually discussed in the present communication there are no undoubted lavas, but andesitic and basaltic lavas have been seen to the south.

As we have said in an earlier section, it is difficult to point to any particular tectonic line responsible for the movements which gave rise to the boulder-beds, their associated phenomena, and finally to the graded bedding of the Upper Cretaceous. The folding of the Cenomanian shales accompanying the sudden intrusion of great blocks often points to movement from the north. Arni drew attention to this. The same author also suggested the existence of a tectonic line of great importance running along the position of the present Belen Dağ. Because of the thick cover of younger rocks in this region we cannot point to Carboniferous rocks and Lower Cretaceous limestones in this region, although they occur along the same line to the north-east.

The much greater extension of the Upper Cretaceous seems to us to suggest the migration of the tectonic line towards the south. During this time it would seem that the eastern coalfield was raised and the sea pushed towards the north. Later still, the sea was pushed from the whole region and in early Tertiary times conditions of deposition were reversed, land existed to the north and sea to the south. This immediately recalls the palaeogeographical conditions existing during the Carboniferous, and one is left in no doubt that the Mesozoic reversal of land-sea relations was accompanied by great and repeated tectonic disturbances.

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DISCUSSION

D. N. WADIA said that he would like to enquire what agency in nature could have transported and dropped the huge boulders and masses of Carboniferous rocks into a Cretaceous deposit under formation. The authors' explanation of its being due to slumping did not seem to answer the difficulty. It must have meant a considerable amount of lateral movement of enormous masses extending over several miles; and faulting, landslides, landslips or slumping by themselves alone did not give a satisfactory explanation.

F. E. WELLINGS recalled a similar occurrence of Carboniferous slumped blocks in Upper Cretaceous marls at Abd El Aziz in North-East Syria, outcropping on the steeper north flank of an asymmetric anticline which had lower Cretaceous as the oldest beds in its core. The geological succession in the nearest deep wells 100 miles away comprized this Carboniferous facies overlain by Permian siltstones and thick Mesozoic (Triassic-Jurassic and Cretaceous) limestones. There was no outcrop of Palaeozoic or any formation older than Cretaceous in the vicinity and no geophysical work had yet been done across the structure or over the surrounding plain, so there was no clue to the position of the buried cliff which could have provided these blocks. They varied in size from small angular slivers to huge slabs and blocks of micaceous sandstone and fossiliferous limestone.

The Lower Senonian in Syria displayed evidence of shallowing emergence with phosphates, bone beds, big oysters, red sands, etc., but this was the only occurrence of exotic blocks and there was no sign of unconformity or tectonic disturbance.

E. B. BAILEY suggested that in such cases tunamis had had their share.

C. I. MIGLIORINI said that the exotic-bearing Cretaceous formation described in the most interesting paper by Prof. McCallien and Dr. Tokay appeared to resemble very closely the "Argille Scagliose" of the Apennines, and the photographs shown on the slides accompanying the paper might easily be mistaken for photographs taken in Italy. In the Apennines there was evidence proving that the shaly matrix had slipped together with the exotics embedded in it. It would be interesting to know whether the same also applied to the Anatolian formation.

CONTRASTS IN ROCK PERMEABILITY AS A MAJOR CAUSE IN ORE DEPOSITION

By R. A. MACKAY

Great Britain

ABSTRACT

The Society of Economic Geologists recently sampled the opinion of a number of geologists as to which subjects it was considered most merited research in the field of ore deposition. The influence of relatively impermeable overlying rocks came eleventh on a long list.

The present writer has long considered this control to occupy a higher degree of importance than it has hitherto been awarded. The purpose of the present paper is to sample a representative number of accounts of ore deposits in order to assess this importance as regarded by leading authorities. For this sampling, Newhouse's symposium on Structural Control has been chosen since it contains a large number of articles included with the intention of covering as wide a variety of types as possible.

The paper features a tabulation of these properties, designed to indicate the importance of the control exercised by an upward reduction in permeability and to indicate where further work is required to arrive at a decision as to whether it is applicable.

It is considered that the essence of the control is that the solvent was able to pass on where the dissolved mineral could not. Attention is drawn to papers which express this view.

THE general principle which this paper enunciates has been published by the author elsewhere (Mackay, 1946) and the present purpose is to relate this earlier work to other publications which seem to be leading in the same direction. An equally important purpose is to allow opportunity for the provision, in discussion, of other examples or references which have escaped the present author.

In the Report of the Committee on Research on Ore Deposition set up by the Society of Economic Geologists (1947), the replies to a questionnaire to leading economic geologists in the United States were tabulated. Out of a list of thirty-six factors suggested, the concensus of opinion placed " Permeability barriers in localization of ore deposits " eleventh in importance.

That numerous ore bodies occur below relatively impermeable barriers is, therefore, well enough known, but the nâture of this relation has received too little discussion considering how common the condition is. On accepted theories of ore deposition, falling temperature and pressure cause deposition from ascending solutions. If temperature and pressure fall are the dominating factors, habitats involving trapping or impounding, beneath relatively impervious barriers, are highly paradoxical, for such habitats are those where circulation is likely to be least and deposition, therefore, scanty. Some of the traps described in the author's original paper on the subject are very complete indeed and the space within them would be one of complete stagnation unless liquid passed away through the impounding barrier. If, however, liquid did pass through the barrier the maximum rate of fall of pressure and temperature (and, therefore, of deposition from solution) should be above an impediment and not below it. But ore bodies do not form where pressure and temperature fall is most rapid; for example, as Spurr has stressed, important ore bodies are rarely at surface. Another fact that is incompatible with the view that deposition is mainly determined by temperature and pressure fall, is that metals which deposit late, or near surface, such as mercury and lead, are less soluble than those depositing deep and relatively early such as tin and copper. This is surely a grave inconsistency.

These paradoxes clearly indicate that one or more important variables have been left out of account in the theories of hydrothermal ore deposition. It is proposed that one such important factor, which

TABLE I. WELL AUTHENTICATED EXAMPLES (From the Symposium on Ore Deposits as Related to Structural Features)

Example No.	Locality	Metals	Authority	" Host Rock "	Impounding Rock	Remarks and Quotations	Page
1	Alma, Colo. London Mt.	PbZnAu	Singewald	Limestone, porphyry	Fault gouge, shale	" The solutions could not penetrate the gouge . . . and migrated to beneath an impermeable shale "	94
2	,, Sheep Mt.		,,	,,	,,	" Sheep Mountain . . . is the apex of a dome "	95
3	Lower Loveland		,,			" an abundance of minor fissures allowed the solutions everywhere to escape beyond the broken ground immediately adjacent . . . but as the fissures did not provide continuous permeability the distance of migration was strictly limited "	95
4	Bross Lincoln	Pb Ag		Limestone	Shale	" The structural picture . . . strongly suggests that the ore forming solutions . . . circulated parallel with and not across the bedding "	95
5	Emerald. B.C.	Pb Zn	Hedley	Tuffs and sediments	Andesite	" Mineralising solutions rose through the shear zone to the relatively massive andesite. It was at this point that they were ponded and an ore-body formed "	158
6	Leadville. Col.	Pb	Loughlin and Behre	Mainly dolomite	Porphyry. Some under shale	" The positions of the ore shoots are determined by impervious porphyry sills and argillaceous beds "	203
7	Tristate Lead and Zinc	Pb Zn	Fowler	Massive sediments	Deformed sediments with stylolites	" The sub-surface structure . . . in which the ore bodies have been found may be likened to that of an oilfield . . ."	206
8	Robinson Dist. Nevada	Cu	Pennebaker	Mainly monzonite porphyry	Flat faults	" This same [' flat fault '] zone forms a roof structure . . . and some function controlling ore deposition is suggested "	128
9	Noranda. P.Q.	Cu Au	Wilson	Rhyolites and rhyolite breccia	Andesite and gougey faults	" The most important structural features (include) the occurrence of most of the ore deposits beneath impermeable rocks which served as a barrier to the further ascent . . . of the emanations "	224

10	Copper Mt. B.C.	Cu	Dolmage	Andesite breccia deformed	Non-fragmental andesite	A massive non-fragmental coarse andesite partially encompasses a zone of fracturing on the edge of a gabbro stock	249
11	Elk City. Id.	Au etc.	Shenon and Reed	Misc. fracture zones	Mainly gneiss	" The surrounding rock was evidently not pervious . . ."	175
12	Bakerville B.C.	Au	Hanson	Sheared quartzite and argillite	Massive, "unyielding," limestone	" Rising solutions would pass easily through the strong fractures but would tend to be trapped in the discontinuous breaks immediately under the impermeable roof "	176
13	Gunner mine. Man.	Au	Lord	Ellipsoidal andesite	Late lamprophyre	" The dyke appears to have acted as a dam to the rising solutions "	253
14	Quartz Hill Divide, Mon.	Ag Pb	Taylor	Limestone	Shale	" The solutions followed the fissures up to the contact, where they followed up it or spread out to form extensive bedded deposits "	215
15	Fluorspar Deposits S. Illinois	(CaF_2)	Bastin	Mainly limestone, often stylolitic	Sediments, mainly argillaceous	Some of the examples are clearly " controlled by relatively impermeable shale horizons, beneath which, by limestone replacement, flat lying deposits have been developed "	187
16	Terlingua. Tex.	Hg	Ross	Limestones, flags. igneous rocks	Relatively impermeable. Usually clay	" Trapping of the solutions beneath relatively impermeable material is a major control "	193
17	Quicksilver. S.W. Arkansas	Hg	Reed and Wells	Sandstone	Shale	" The shale remained impervious (after deformation) to the ore forming solutions "	195
18	Tombstone, Arizona	Ag Au etc.	Butler and Wilson	Limestone	Shale	" Incompetent shale overlying competent limestone and 'novaculite' provided an impermeable cap that tended to prevent the further upward migration " and led to the ore bodies in the rolls and drag folds of the anticlines.	201
19	Cobalt, Ontario	Ag etc.	Moore	Cobalt series and Keewatin	Diabase sill	" The occurrence of so large a percentage of ore beneath the sill points to the influence of this impervious body in checking the ascent of the solutions "	250
20	Japanese Epithermal Deposits	Au Cu	Watanabe	Miscellaneous at different localities	Various but less brittle than the host	" The effect of impervious strata " is invoked. Where a shale is more mineralised than a tuff it is shown that the former is the more brittle of the two in this instance	236
21	Rio Tinto, Spain	Cu	Williams	Porphyry	Slates	The author includes as a control the "damming influence of the relatively impervious slates "	258

has not been credited with nearly enough weight, is to be found in the differences in relative permeability which the ore solutions encounter in their upward path. It is not suggested that falling temperature lacks importance, but it must be properly related to other variables of which differential penetrability is one. Doubtless ease of penetration is itself affected by temperature.

It has been clearly demonstrated by Freundlich and elsewhere in the literature that some ions can pass small apertures which constitute a barrier to others. There is, in fact, a given aperture size which is impassable to a specific ion. This was known sixty years ago. It is obvious that such a phenomenon must have application to geology, for the crust of the earth, through which we know solutions to have travelled, constitutes an environment of small apertures. More observation and experiment are required to decide how great a part the phenomenon has played but it is logically certain that it must have been operative.

The author considers this differential passage of ions an adequate factor to reconcile many of the paradoxes mentioned earlier. The water has passed on through the barrier which has impeded the passage of the metals.

TABLE II

EXAMPLES WHERE THE PRINCIPLE APPEARS TO APPLY OR IS CONTRIBUTORY

No.	Locality	Author	Metal	Country rocks "Host"	Country rocks "Trap"	Page
1	Central Dist., New Mexico	Knopf	Zn	Limestone	Sediments arenaceous and argillaceous	67
2	Yerington, Nevada	Knopf	Cu	Limestone	Garnetite	65
3	Republic, New Mexico	Schmitt	Zn	Limestone	Shale	76
4	Hanover ,, ,,	,,		,,	,,	
5	El Cobre, Durango, Mexico	,,	Au	Jasperoid limestone	Limestone overlain by tuff	78
6	Flathead, Montana	Shenon	AgPb	Latite porphyry	Massive Latite and volcanics	134
7	Balmat, N.Y.	Brown	Zn	Limestone	Siliceous bands of less porosity	171
8	Aspen, Colorado	Vanderwilt	AgPb Zn	Mainly limestone	Siliceous sediments	221
9	Sherrit Gordon, Man.	Derry	CuZn	Acid gneiss	Basic gneiss	
10	Boliden, Sweden	Ödman	Cu	Brittle volcanics	Drag-folded schists	166
11	Hedley, B.C.	Knopf	Au	Mainly porphyry	Sediments	69
12	Sheep Creek, B.C.	Walker	Au	Quartzite	Argillite and phyllite	177
13	Little Long Lac, Ont.	Bruce	Au	Arkose	Greywacke	101
14	McLeod Cockshutt, Ont.	,,	,,	Porphyry	Sediments	101
15	Rakeoff Mine } Front Range, Col.	Lovering	Misc.	Granite	Schist	90
16	Wellington ,, } Front Range, Col.	Lovering	Misc.	Quartzite	Shale and fault relation	90
17	Lake Superior Silver Thunder Bay, Ont.	Bruce	Ag	Diabase or brittle rock	Shales and greywacke	101
18	Climax Molybdenum, Col.	Vanderwilt	Mo	Granite	Shale. Pre- and post-mineral fault	
19	Pewabic, New Mexico	Schmitt	Au	Limestone	(1) Shale (2) Intermediate Sill	75
20	Beatson, Alaska	Bateman	Cu	Meta-sediments	Fault plane	147
21	Mother Lode, Cal. Misc. mines	Whitehead	Au	Slate	Greenstone-slate contact	178
22	Consolid Gold Mines, Kirkland, Ont.	Derry	Au	Competent basalt porphyry	Flow tops and tuff bands	183
23	Bralorne Ore-bodies, B.C.	Joralemon	Au	Diorite	Shaly sediments	255

It has been shown (Mackay, 1946) that ions which penetrate most easily are hydrophobic and those which are most easily held back are hydrophillic. In the series Pb, Cu, Sn, the ions of the metals are progressively more hydrophyllic. Thus tin would be most easily held back, by relatively large apertures, while lead would migrate until it encountered a tight barrier. Such is their order of deposition in nature.

The physical chemistry of the process and numerous examples of trapping and impounding are to be found in the papers listed at the conclusion of this contribution and in the bibliographies of those papers. It is proposed here to consider how prevalent the condition is. To avoid bias in the choice of examples it was decided to sample a standard work including a large number of deposite chosen for a general review of structure without regard to any particular theory. Newhouse's Symposium " Ore Deposits as Related to Structural Features " (Newhouse, 1942) was regarded as most suitable to this purpose.

In this volume the various authors have referred directly in twenty-one cases to impounding, or to the influence of containing walls (mainly hanging) or to barriers. In a further twenty-three cases the authors' descriptions are such that impounding would clearly seem to be one of the factors in ore deposition. In the remaining cases data are not full enough to form an opinion, or the deposits are not hydrothermal in origin and are, therefore, irrelevant to the discussion. Table I lists the first category of properties with details and remarks, and Table II the second category without comments.

In our present state of knowledge regarding the permeabilities of rocks and fissures it is clear that impounding will only be noted where there is a good observable contrast between the rocks. It seems likely that other cases exist where the rocks have permeability contrasts which are not readily observed, such as a decrease of effective fracturing. This is particularly likely to be applicable in the case of the larger hydrated ions such as tin and copper. It is significant that the barrier contrast is almost always conspicuously apparent in the case of mercury. the hydrated ion of which is small. It is also very commonly observed in the case of lead which is also relatively small, though less so than mercury.

In conclusion, it is urged that it is not enough to know that some ores occur beneath barriers or within traps. The establishment of the reason for this is essential in order that the phenomenon can be used as one of the bases in the reasoning applied to ore search. But before this reason can be firmly established, research is necessary into the permeability of rocks relative to specific solutions.

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DISCUSSION

W. F. JAMES asked whether the author considered the principle applied to Noranda Mine and, if so, what constituted the barrier.

R. A. MACKAY replied that he considered it did apply, and that the converging Horne and Andesite faults were impermeable walls, and the included andesite nose of the pitching anticline was the relatively impermeable cap above the brittle fractured rhyolite area in which the ore lay. The matter was discussed in the Mining Magazine, 1948, where the opinion of another writer on the subject was also given.

W. F. JAMES said that this was a perfect example of the phenomenon.

E. O. TEALE asked if the author, from his intimate experience of the auriferous veins on the Lupa goldfield in Tanganyika, where practically only the roots of the mineral veins remained, had been able to apply his views successfully.

R. A. MACKAY agreed that the Lupa veins were largely root-like and that evidence concerning impounding was therefore often difficult to interpret, much of the original cover having been removed. However, in spite of the removal of so much of the original structure, it was significant that a number of the veins were associated with relatively impermeable rocks such as Loveridge's Chipooka, Tanganyika Minerals, and Evening Star, which were at a low inclination beneath diorite or schist and above more brittle gneiss; Twiga and Zumbi below a hanging wall consisting

of a basic dyke; and Maher's below a gougey pre-mineralization fault. In fact, of some forty small mines considered, four were in diorite or schist, four showed no vestiges of any rock other than the containing granite or gneiss, and the rest were associated with an overlying rock which was less competent than the main country in which the vein occurred, or had vestiges of such a rock in an overlying position.

G. A. SCHNELLMANN said that economic geologists used the term " favourable bed " without in most cases knowing what it implied, but often with a vague suggestion that chemical activity was involved. So many cases were paradoxical on this basis that he had come to believe there was no such thing as a " favourable " bed in the absolute sense. The intrinsic properties of a bed were not as important as the environment, e.g. in the United Kingdom three areas of mesothermal lead-zinc mineralization might be considered. In West Wales, the " favourable " bed was the Frongoch sandstone, overlain by the Cwmystwyth formation which consisted of shales with overlying grits, which were barren. In West Shropshire, however, the Mytton Grit was overlain by the Hope Shale, and there grit was a favourable bed. The speaker suggested that grit was, therefore, neither favourable nor unfavourable in an absolute sense, the dominant factor being the overlying shale.

In the Shropshire area the Hope Shale was overlain by the Stapeley volcanic ash series, which was barren. In the Lake District, on the other hand, the Borrowdale volcanic series (ashes and lavas), formerly covered by Carboniferous basal shales, were favourable. Hence again, volcanic ash was neither favourable nor unfavourable in an absolute sense, but became favourable when overlain by a shale. Those specific examples appeared to the speaker to support Mackay's contention very strongly.

R. A. MACKAY replied that the contribution offered strong evidence that it was the contrast of the pairs of rocks mentioned which was the operative control. In each case deposition was in the more penetrable of the pair. The author thanked Dr. Schnellmann for those most interesting and convincing data.

C. A. U. CRAVEN said that Dr. Mackay's theory offered a possible mechanism which seemed to throw further light on the manner and position in which ore deposits were formed. However, it was difficult to see how the theory which he had proposed fitted the observations at Halkyn which showed that the ore-bodies tended to lie under the highest points of the shale barrier. A difference in permeability would have to exist to cause the ore-body to form in the anticlines according to the proposed mechanism. Such a change in permeability might occur in folding when one considered the difference in resistance to erosion which caused mountains to occur on synclinal structures.

The speaker thought that that point was of importance, since, should the ore in general occur at the higher points of a barrier, other things being equal, the fact supported by the theory could become a valuable ore-finding tool.

R. A. MACKAY replied that the veins of the ore-bodies at Halkyn, and in similar mineral fields in Slovenia and Italy mentioned in the list of references, seemed to be on the routes by which ascending solutions would tend to *leave* the structures concerned. In those cases the depth to which mineralization penetrated was commensurate with the amplitude of the folds. It was not considered that deposition should necessarily take place at the barriers; these barriers served to increase concentration in general for some distance below. But other factors were of course operative as well as the " hypofiltration " of the solution. Early deposition would reduce permeability near the barrier by reducing pore size, and so lowering the zone of deposition. The ability to penetrate at all was probably controlled by what Wisser called dynamic control, that is fracturing, which was pene-contemporaneous with deposition and extended intermittently over the same period. Thus new fractures and new barriers were continually arising in the zone of deposition.

Anticlinal areas in a competent rock beneath an incompetent one were likely to be more tensional than the synclinal areas, and hence to be open textured, and thus more favoured channels. Newhouse had not overlooked that solutions tend in the vast majority of cases to rise within an anticline. But it was hardly likely that they would do so if there was no escape for the solvent, and most unlikely that the bulk of the precipitation would be below the barrier if the solute could penetrate it. It would seem that a combination of those factors would be necessary for ore deposition. The purpose of the speaker's paper was to introduce an insufficiently considered but often indisputable factor, not to suggest that it alone was responsible for ore deposition. Mr. Craven had drawn attention to what was probably a very necessary adjunct, an increase of fracturing in domes and anticlines.

R. M. SHACKLETON said that by Dr. Mackay's theory zoning in ore deposits might be explained, one could say, by supposing that nature provided a set of sieves which trapped ions of certain dimensions. It was difficult to imagine how such a series of natural sieves could be so conveniently arranged in order, those corresponding to beds with the largest pores below and those with the smallest pores above.

R. A. MACKAY said that Dr. Shackleton's picture was clearly too convenient! If deposition were always *dispersed* in the series Sn. Zn. Pb. Hg., it would be a conclusive argument against impounding. But, to retain the analogy of sieves, if a small mesh sieve were the first to be encountered by a mixed solution, then all the metals would deposit, resulting in the telescoped deposits, of which Bolivian tin was one of many examples. It would be evidence against the conception if, for example, tin, which required only a coarse sieve, were ever deposited above copper (in other than subsidiary amounts due to a broken screen); or lead above mercury, which required the finest of sieves. The speaker knew of no such anomalies. Either the general sequence was preserved as the solutions passed from the more brittle and permeable to the more incompetent sedimentary rocks, or the metals became deposited in groups, as telescoped deposits.

P. WILKINSON referred to the fluorspar deposits of Masson Hill, Derbyshire. In one exposure mineralization had taken place above the local structural control, the Derbyshire Toadstone, an exception to the general rule of the district.

Prior to fluorization, dolomitization had taken place and the second mineralization had proceeded almost exclusively in the altered areas. The preference was presumably controlled by the greater porosity of the dolomite, which was visibly porous.

R. A. MACKAY thanked Mr. Wilkinson for his example, which seemed to be an apparent exception in an area where the principle normally applied.

D. J. BURDON asked Dr. Mackay whether the position of the ore on the crests of the anticlines, as seen in the example from Halkyn Mine, might not be more satisfactorily explained by the occurrence of zones of decompression rather than by the relative impermeability of the overlying slate bed. Volumes of decompression occurred along the crests of anticlines beneath the more competent beds—the saddle-reefs of Bendigo being a well-known example of deposition in such a decompression zone—and they would, in the example under discussion, also appear to be the dominant factor; though, of course, means of escape for the transporting fluid should not be overlooked.

R. A. MACKAY replied that Mr. Burdon had raised much the same point as Mr. Craven. The author would, however, suggest that whereas decompression might be a correct diagnosis as regards the anticline contrasted with the syncline, there was not a zone of decompression as regards the sub-barrier area as a whole. The very existence of a barrier contradicted the idea of decompression, which was not a necessary attribute of an open texture. The author therefore did not consider this open texture in an anticline case could be regarded as an alternative to the postulated action of the shale, but only as an ancillary factor.

GROUND WATER PROBLEMS AND RESEARCH IN THE UNITED STATES

By O. E. MEINZER

U.S.A.

ABSTRACT

The United States has a very wide range of geologic and hydrologic conditions, and affords a large, diversified, and interesting field for scientific study of ground water. W. F. Guyton, U.S. Geological Survey, has shown average daily use of ground water amounting to 20,000 million U.S. gallons, of which 10,000 million is for irrigation, 3,000 for public supplies, 5,000 for industries having private wells, and 2,000 for rural use. Financial support for scie tific work has resulted from great increase in use. A few hundred scientists (geologists, engineers, physicists, and chemists) in the United States now devote all or most of their time to scientific study of ground water, including fully 200 in the Geological Survey.

U.S. scientists learned their first lessons in geohydrology from France and other European countries. Ground water investigations have been in progress since middle of 19th century but largest contributions to the science have been made in last twenty-five years—along a broad front but especially in the application of hydrodynamics. About 1,300 technical publications relating primarily to ground water have been prepared by U.S. Geological Survey, State Geological Surveys, and other co-operating agencies. A recent study outlines further research needed in several phases of the subject.

THE United States has a very wide range of geologic and hydrologic conditions. Especially is this true if the three territories are included—Puerto Rico, with its cavernous limestones; Hawaii, with its active volcanoes and distinctive volcanic hydrology; and Alaska, with its large glaciers, permanent frost, and other polar features. It contains rocks of virtually every age, from Archean to Recent, of almost every variety of sedimentary, igneous, and metamorphic origin, with great variety and extremes of hydrologic conditions. It contains all kinds of major and minor features of geologic structure, with their control over the movement of ground water, artesian conditions, and salt-water intrusion. It contains mountain ranges, high plateaus, great plains, and extensive delta and other lowlands, each with its distinctive hydrology. It contains the southwestern region of great though not extreme aridity, the vast semiarid region of the West; the subhumid and humid central and eastern parts of the country, with average annual precipitation along the Atlantic Coast ranging between 40 and 60 inches; the humid northwestern region, in some parts of which the precipitation averages more than 100 inches a year; and the Hawaiian Islands, where semiarid localities occur close to localities having an annual precipitation of a few hundred inches. It contains regions of subtropical climate, where evaporation and transpiration balance even fairly large rainfall, and regions of progressively colder climates, where there is notably less evaporation and transpiration and hence less aridity even with smaller precipitation. It contains California, where precipitation and ground water recharge occur chiefly in the winter season when evaporation and transpiration are at a minimum; other parts of the Southwest where the meager precipitation occurs chiefly in summer, when most of it is returned by evaporation and transpiration without opportunity for ground water recharge; the humid Southeast, with mild climate, where ground water recharge occurs in each season of the year; and the cold northern parts of the country, where the soil is frozen during the winter and ground water recharge occurs chiefly in the spring breakup.

The greatest quantities of ground water in the United States are pumped for irrigation and other uses from the sand and gravel strata of the extensive Tertiary and Quaternary alluvial deposits derived from the western mountain ranges and laid down in the broad intervening valleys, along the Pacific Coast, and on the Great Plains east of the mountains. The largest of these valleys is the Great Valley

of California but very large quantities of water are also pumped from some of the other valleys, the coastal areas of Southern California, and the Great Plains.

Equally productive and also extensively utilized are the great deposits of sand and gravel that were washed out from the Pleistocene ice sheets whose fronts extended for 3,000 miles across the northern part of the country. Near the west end are the exceedingly clean and permeable gravels, as those in the Spokane area, carrying vast underflow; near the east end are the glacial sands of Long Island, which for more than half a century have yielded very large supplies to the metropolitan area of New York; and between these are innumerable sand and gravel trains of existing and ancient valleys in the Mississippi drainage basin, which are also very extensively utilized.

Ranking with these two great systems of aquifers, are the sand, gravel, and limestone formations of the Atlantic and Gulf Coastal Plain, ranging in age from Lower Cretaceous to Quaternary. This coastal plain extends from New England to the Rio Grande and on into Mexico. It includes the sands and gravels of the Mississippi Embayment, the very permeable limestones of Florida, and the large limestone springs of Florida and Texas. It furnishes the public and industrial water supplies of Houston, San Antonio, Memphis, and many other cities, and large supplies for rice and other irrigation.

Other important sources of ground water are the Paleozoic sandstones and limestones of the Interior, which are widely utilized and include the productive Roswell artesian basin; the Cretaceous formations of the Great Plains and western mountain and plateau region, which yield water supplies in many places and form the large Dakota artesian basin; and the Tertiary and Quaternary basalts, which in Idaho, California, and Oregon, give rise to the largest springs in the United States, and which in Hawaii yield very large supplies to wells. In addition there are many other formations, widely distributed and ranging widely in age, which yield supplies that are less copious but are nevertheless very valuable to the localities in which they occur.

There are also extensive areas in which ground water supplies are meager and in parts of which it is difficult or impossible to obtain enough water even for rural needs. In the areas of pre-Tertiary igneous rocks and of gneiss, schist, quartzite and other metamorphic rocks, such as the Piedmont area, in the East, only small yields are obtained from most wells and there are some complete failures. Even more difficult and uncertain conditions are found in some of the Paleozoic limestone areas of the Southeast and in certain areas of soft, dense Paleozoic and Cretaceous shales in the Interior that are not underlain by any water-bearing formation or only by formations containing salty water. In these areas the towns generally have surface reservoirs and the farms depend on rainwater cisterns and on small reservoirs for livestock.

It is evident from what has been said that the United States affords a vast, diversified, and interesting field for the scientific study of ground water. However, the financial support for such study has not come from funds devoted primarily to scientific research but from funds appropriated by the Federal and State Governments and some municipalities and irrigation districts for strictly utilitarian purposes.

One of the notable features of the agricultural, municipal, and industrial development of the United States is the vast use that is being made of the country's water supplies, the rapid increase in the use of water in recent years, and the trend forecasting still greater use in the future. This notable increase in water use is occurring in the arid West, the industrial East, and indeed all parts of the country. It involves both surface water and ground water, and in many areas extensive use is made of both sources of supply.

Surface water has the advantage of occurring in large and concentrated quantities and is therefore utilized extensively for large irrigation projects and for the public supplies of the large cities. Ground water, on the other hand, is more widely distributed and hence is more available for the supplies of the smaller towns and rural regions, small and moderate-sized industries, and irrigation in small-scale units. The cost factor generally favors surface water for the large projects and ground water for the smaller projects, and, of course, depends to a great extent on the local ground water and surface water conditions. In many cities the public supply is obtained from surface sources, whereas many of the industries are supplied from private wells, largely to reduce the cost. Most of the great number of

new water supplies needed in the last war were obtained from ground water because in favorable places the supplies could be developed quickly and with the use of relatively little labor and material by sinking wells.

Surface water, in general, has the advantage of being less highly mineralized than ground water. Many of the ground waters are too hard to be acceptable for public or industrial use and are not readily softened, and in some the ratio of sodium to calcium and magnesium is too high for successful use in irrigation. On the other hand, ground waters have the advantage of being relatively free from pollution, so that with proper precautions they can generally be safely used for small towns and farm homes where adequate purification of surface waters is not practicable. Moreover, ground waters have the advantage, important in many industries, of having nearly constant mineral content, whereas surface waters fluctuate greatly in this respect. Furthermore, the ground waters have the advantage of having almost constant temperature and of being relatively cool in summer when surface waters are warm. This characteristic has become highly valued in many industries for both cooling and processing. A fundamental advantage of ground water is the storage capacity of the aquifers, which makes the ground water available when needed. Thus a basic principle in the utilization of the total water resources is to coordinate the use of surface and ground waters in such a way as to obtain the maximum benefit from the storage capacity of the aquifers. Such coordination has great possibilities, which, however, can be realized adequately only when there is better cooperation than at present.

In a survey recently made by W. F. Guyton, of the U.S. Geological Survey, it was found that in 1946 the average daily consumption of ground water in the United States amounted to about 20,000 million U.S. gallons a day—a large increase over the estimates ten years earlier. This consumption is equal to approximately 80,000 million liters or 80 million cubic meters a day. All except a small part of this water was pumped from wells. It amounts to about 150 gallons a day *per capita* for the entire population of the country.

It was found that about 10,000 million gallons was used for irrigation—in California and Arizona, largely for citrus and other valuable crops; in New Mexico, Texas, Nebraska, Utah, and other western States for various crops; in Hawaii, for sugar cane; in Arkansas and Louisiana, for rice; and in Florida and other eastern States, largely for garden truck. The extension of irrigation in the East by pumping from wells and from small surface reservoirs is likely to be an important future development.

About 3,000 million gallons of ground water are used daily for the public supplies of about 9,000 cities and towns; about 5,000 million gallons for industrial establishments that have private wells; and about 2,000 million gallons to supply most of the several million farm homes, the small rural communities that do not have public waterworks, and the many millions of cattle, swine, sheep, horses, and other animals throughout the country. In all three of these categories (public, industrial, and rural supplies) there has been large recent increase in consumption with prospects of further increase in the future—for example, for extensive air-conditioning, for large paper mills established in the South, and for running water and bathroom facilities in rural homes made practicable by rural electrification.

The extensive demands for ground water have led to surprisingly heavy demands for scientific investigation of the ground water resources. Obviously, with so much activity, difficult problems of development and overdevelopment have arisen in many localities, creating demands for help from technically trained ground water specialists. The failure of flowing wells, the decline of water levels requiring the lowering of pumps, the appearance of salty water in fresh-water wells cause a panicky feeling of helplessness on the part of the water users and impel them to seek for help. In the competition between cities and States for new industries, it has become evident that for many new establishments reliable ground water supplies are desired and that a detailed government report on the ground water resources of an area is a substantial aid in securing such establishments. Moreover a great number of leading men—consulting engineers, officials of the American Water Works Association,

Governors, State engineers, State geologists, members of Congress and of the State legislatures, etc.—have come to realize the importance of wise action to obtain the full benefits of the country's ground water resources and to avoid disastrous overdevelopment. They appreciate the basic need of thorough quantitative ground water surveys.

The principal agency in the United States for making ground water surveys and conducting research in ground water hydrology is the Ground Water Branch of the Water Resources Division, in the U.S. Geological Survey, in cooperation with the State Geological Surveys and other governmental agencies in nearly all of the States and in Hawaii and Puerto Rico. The Ground Water Branch and its cooperating agencies have an aggregate annual budget of around a million and a half dollars and a staff of about 200 geologists, engineers, and physicists who devote their entire time to ground water investigation. In addition are numerous field assistants, observers, draftsmen and clerks. In addition also are the chemists of the Quality of Water Branch of the Water Resources Division, who work on both surface and ground waters. There are also considerable numbers of ground water geologists and engineers in other bureaus of the Federal Government, other State agencies, chiefly in California, Illinois, and Missouri, and municipal and district water departments; and also a small number of consulting geologists and engineers, largely trained in the Ground Water Division, who devote all or most of their time to ground water problems. It appears that the United States is unique among the countries of the earth in having a few hundred scientists and engineers who are ground water specialists and who devote essentially all, or at least most, of their time to the study of ground water.

All except a small part of the funds appropriated to the Water Resources Branch of the U.S. Geological Survey are limited to use in cooperation with State or local governmental agencies. This policy has secured the important benefits that result from cooperation, but, on account of the very small amount of unrestricted funds, it has placed the emphasis on the application of the science to specific areas rather than the development of basic principles and effective methods. This is also true of the ground water work conducted by most other Federal bureaus and by States, districts and private consultants. To some extent it has been a cart-before-the-horse policy, and it accounts for the comparatively slow progress in basic research in the ground water science for the size and caliber of the technical staff. The problem has, however, been recognized in the Ground Water Branch for a long time, and encouragement has been given to all members of the staff to contribute to the development of basic principles and improved apparatus and methods in connection with all investigations and surveys.

The geologists and engineers in the United States learned their first lessons in geohydrology and its practical application from the European geologists, engineers, physicists, and chemists, and they are still receiving substantial help from the ground water researches that are conducted in other countries. Hydrology and geohydrology had their origin and early development in Europe, and nearly all the European countries have made contributions to the science of ground water and its practical application. This is true of the small as well as the large countries. In the United States we have made use chiefly of the results that are published in the three languages with which we are most familiar, namely English, French, and German. Fortunately for us the smaller countries generally publish their results, at least in abstract form, in one or more of these languages, but we have probably not benefited proportionately from the important ground water researches that have been made in Italy and Russia.

In the United States we think of da Vinci, in Italy, and Palissy, in France, in the 15th and 16th centuries, as hydrologic pioneers, and of Perrault and Mariotté, in France, and Halley, in Great Britain, in the 17th and 18th centuries, as the founders of hydrology. We think of William Smith, early in the 19th century, not only as the father of English geology but also as a notable pioneer in applying geology to the study of ground water. We consider that the leading part in the development of the science of ground water and its application was taken by the scientists and engineers in France, beginning about the middle of the 19th century, but that important work was also done in this field at the same time or a little later by the scientists and engineers in Germany, Italy, Austria, Russia, Great Britain, Holland, and other countries of Europe. Fifteen years ago the author of this paper had the

courage to publish a paper entitled *The history and development of ground water hydrology* (Meinzer, 1934). In that paper are listed the names of numerous scientists and engineers who, from the American viewpoint, have made outstanding contributions to the science of ground water. The writer would be glad to be informed of errors that were made in the evaluation of these men and especially as to any other outstanding geohydrologists who should have been recognized.

In the United States not much systematic ground water work was done before the middle of the 19th century, but a large amount of work was done in the last two or three decades of the 19th century and the first few years of the 20th century. Then there was an unfortunate lapse of interest and available funds, and apparently a feeling that the necessary ground water surveys had been largely completed. This condition lasted until about the First World War. The writer did his first ground water work in 1906 and was placed in charge of the Ground Water Division in 1912, when the staff of the division consisted of only a very few inexperienced geologists and an annual budget of only about $10,000. Since the First World War there has been a steady increase in interest in ground water and corresponding increase in available funds and the quantity and quality of ground water investigations. The growth was gradual but persistent until in the last few years, when it became very rapid and there came to be a new appreciation of the great scientific and economic significance of this subject.

The early ground-water work in the United States consisted largely of the application of geology in areal reconnaissance surveys. Near the turn of the century notable work was done by Slichter, King, and others in interpreting the results that had been obtained in Europe in the hydrodynamics or hydraulics of ground water and in making new contributions. Important hydrologic results were also obtained in this period by Veatch and others. In the ensuing years progress was made in outlining the subject, classifying the ground water concepts, and developing quantitative methods. In 1917 and 1918 a survey was made of desert watering places in California and Arizona, and much progress was made in the study of ground water conditions in arid regions, especially concerning the phreatophytes, which send their roots down to the water table. A new period of intensive ground water study may be said to have begun about 1923. In or about that year the water-supply papers appeared on *The occurrence of ground water in the United States with a discussion of principles* (*No.* 489) and *Outline of ground water hydrology with definitions* (*No.* 494), the hydrologic laboratory was established in the Geological Survey, automatic water-stage recorders came into use for intensive hydrological studies, and young men trained as hydraulic engineers were added to the staff of the Ground Water Division, which had previously consisted entirely of geologists. In the last twenty-five years the effort has been made to develop the study of ground water along a broad front, to reinforce all phases of the subject with an adequate body of reliable data, to develop precise and effective field methods, and to apply the results to the solution of the practical problem of optimum utilization in specific localities. Doubtless the most important progress has been made in hydrodynamics—the principle of the compressibility and elasticity of artesian aquifers, the application of the laws of heat flow to nonequilibrium conditions or unsteady flow of ground water, etc.

It is now recognized that the perennial yield of ground water in any area is not a rigidly fixed quantity but can in many places be increased by proper location of wells, artificial recharge, etc. Thus to obtain maximum use of the ground water of an area there should be a thorough ground water survey of the area, the services of consulting geologists and engineers to direct the ground water developments, and equitable and effective State laws to control the use of ground water.

In 1947 the U.S. Geological Survey published Water-Supply Paper 992, which is a bibliography and index of publications relating to ground water prepared by the Geological Survey and co-operating agencies. It lists 1,777 papers, of which about 1,300 relate primarily to ground water. Unfortunately it was not practicable to include in this bibliography the widely scattered ground water literature from other sources.

In a recent report (Meinzer, 1947) the writer summarized the further research needed in ground water under the following headings: (1) hydraulics of ground water; (2) physics of soil moisture; (3) artificial recharge; (4) geophysics of ground water head and run-off, that is, the hydrologic

and geologic interpretation of the great quantity of water-level records in relation to precipitation and runoff; (5) geophysical methods of exploration, including electric logs of wells, etc; (6) geologic texture and structure in relation to ground water; (7) geochemistry of ground water; (8) salt-water balance, and (9) bacterial and industrial pollution of ground water, and the purifying capacities of the rocks.

Water has been involved as a primary agency in most of the geologic processes in the history of the earth. Thus, hydrology should be regarded as a basic science underlying geology, and it should be included with petrology, mineralogy, and paleontology in the curricula of the geology departments of the universities and technical schools. The geologists in the United States are becoming conscious of the fact that this basic subject has been strangely neglected in our geologic curricula, and that this neglect has resulted in serious handicap in the development of the science of geology. Departments of geology, as well as departments of engineering, are now introducing courses in hydrology and especially geohydrology. This movement should result in further effective research in the subject, with especial application to geologic problems.

In conclusion it should be said that while the principal scientific work on ground water has been done in the European countries and the United States, the other countries of the world also have great resources in ground water and have made important ground water studies—chiefly in the nature of surveys rather than research. There are geologists and engineers in almost every country who are interested in ground water. With encouragement and help they should in the future make large scientific contributions to the subject.

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Note.—The annual budget and staff of scientists devoted to ground water investigation have increased substantially since the late Dr. Meinzer presented this paper in 1948. During the 1951 fiscal year the co-operative investigation budget was about three million dollars, and the number of scientists was about 300.

RICERCHE TETTONICHE NELL'APPENNINO SETTENTRIONALE

di G. MERLA

Italy

ABSTRACT

The results are submitted of the field work carried out in the northern Apennines by the " Centro di Studi per la Geologia dell'Appennino", which the National Council of Research of Italy has established at the Geological Departments of the Universities of Florence and Pisa.

From a tectonic standpoint, in the northern Apennines it is expedient to consider an allochthonous formation, the so-called " argille scagliose," and an autochthonous basement. The lâtter is formed by a sequence extending from the Upper Trias to the ?Oligocene, that is, to the " Macigno " sandstone. The north-eastward displacement of the allochthonous cover may be accounted for, in agreement with Migliorini's and Signorini's ideas, by means of extensive landslips brought about by the shifting of the tectonic slopes in the basement. Attention has mainly been given to the basement tectonics. Thus far a structure or rather a chain of vicarious structures has been worked out, stretching north-westwards from Mount Cetona to the Cerreto Pass over a length of 150 and a width of 5 to 15 miles. There are reasons to believe that the northern Apennine is built up by several such structures successively formed north-eastwards. The above structure is everywhere governed by faults. Normal faults are visible on its inner (Tyrrhenian) side, inverse faults on its outer (Adriatic) side. This ascertained association of faults, which may concur in bringing about an upheaval, seems to afford a confirmation of Migliorini's views on the rôle of composite wedges in orogeny. On the north-east slopes thus formed, landslips and consequent tectonic denudation occur, affecting not only the " argille scagliose " but also the " macigno " and the " scaglia " at least.

NEGLI ultimi due anni gl'Istituti di Geologia delle Università di Firenze e di Pisa hanno dedicato buona parte della loro attività alla tettonica dell'Appennino Toscano. Questo congiunto lavoro è stato sostanzialmente facilitato dal Consiglio Nazionale delle Ricerche d'Italia colla istituzione, nel 1947, di un " Centro di Studi per la Geologia dell'Appennino," che inizia ora le sue pubblicazioni nel Bollettino della Società Geologica Italiana (Merla, 1948).

Fra i risultati finora raggiunti emergono già alcuni tratti d'interesse generale, che appunto formano oggetto della presente comunicazione. Questa riguarda specialmente l'area studiata dai geologi fiorentini; in particolare, si fonda largamente sui rilievi e sulle conclusioni dei miei collaboratori dell'Istituto Geologico di Firenze, dott. Azzaroli, Losacco e Valduga.

E' noto che, come per molte altre catene montuose, due schemi tettonici contrastanti sono stati proposti per spiegare la struttura e l'origine degli Appennini. Secondo l'opinione più antica, gli Appennini sono il risultato di un piegamento armonico, senza ricoprimenti o masse alloctone di una qualche entità. I partigiani dell'opinione più recente, invece, hanno cercato di applicare agli Appennini la teoria delle falde di ricoprimento, che nel frattempo aveva trovato largo favore nelle Alpi.

Né l'una né l'altra dottrina regge alla prova dei fatti. La teoria delle falde, cosi come è stata proposta per gli Appennini, sembra oltrepassare i limiti delle possibilità fisiche, in quanto implica che coltri rocciose (nel caso meccanicamente più favorevole spesse da due a tre km ed estese per parecchie decine!) debbano aver viaggiato dal Tirreno fino al margine adriatico dell'Appennino, o magari in senso inverso secondo altri autori, sotto l'azione di una spinta da tergo. In linea di fatto, non esiste negli Appennini alcun serio indizio a favore di consimili spostamenti. Desidero lasciar fuori da questa affermazione certe aree particolari come le Alpi Apuane, che non conosco abbastanza. Ma se veramente vi si osservano sovrapposizioni tettoniche sul tipo delle falde, esse avrebbero in ogni caso un'estensione del tutto locale (relativamente all'area della Toscana), tanto da non potere in nessun modo giustificare il termine, p.es., di " Toscanidi," che ancora vive nella letteratura, per quanto,

nell'ipotesi più favorevole, affatto improprio. Confido che queste opinioni mi possano venir perdonate tanto più liberalmente in quanto io stesso in un precedente lavoro (Merla, 1933) ho usato correntemente i termini di " falda " e di " Liguridi " per la coltre alloctona delle" argille scagliose." Questa è peraltro, secondo un'opinione oggi diffusa fra i geologi italiani e che mi sembra ben fondata, un insieme di materiali franati e scivolati per gravità in tempi diversi sui pendii orogenici propagatisi da occidente ad oriente (Migliorini, 1940, pag. 19 e nota; Signorini, 1940, pag. 370-371). Non mi sembra quindi corretto applicare alle argille scagliose il termine di " falda di ricoprimento " (o i suoi equivalenti nappe de recouvrement, thrustsheet, Ueberschiebung) che pertinentemente dovrebbe limitarsi a corpi tettonici quali quelli rappresentati negli spaccati classici delle Alpi, cioè falde di 1° genere o ultrapieghe, con fianco normale e rovesciato, e falde di 2° genere col solo fianco normale, e ai loro termini di passaggio: corpi tettonici che sembrano essere concettualmente legati, nella loro meccanica, all'idea di un moto per spinta da tergo. Ma lasciando pur da parte la nomenclatura, basterà sottolineare la grandissima differenza fra il concetto di "coltre alloctona" da frana e scivolamento gravitativo (per la quale altri proporrà un termine appropriato) e quello di " falda ": quest'ultima mi sembra debba essere un corpo tettonico unitario, che abbia una sua compagine strutturale press'a poco come un sistema rigido, e si sia mossa perciò contemporaneamente in tutte le sue parti. Nessuno di questi caratteri conviene alle argille scagliose. Le " Toscanidi," così come sono state concepite, sarebbero, a differenza dalle argille scagliose, indubbiamente una falda.

D'altra parte, la dottrina tettonica pre-faldistica richiede una duplice e fondamentale correzione. In primo luogo, l'orogenesi dell'Appennino è stata, dunque, accompagnata dalla graduale formazione di una coltre alloctona superficiale, le cosiddette argille scagliose, di struttura affatto caotica e infarcita di masse esotiche di provenienza occidentale, come le ofioliti e le arenarie con Ammoniti e Inocerami (" pietraforte "). L'ammettere che le argille scagliose siano dovunque alloctone da occidente, non implica dover ammettere che ogni loro porzione sia di provenienza tirrenica come le ofioliti e la pietraforte. Al contrario, vi sono buone ragioni per ritenere che le argille scagliose durante il loro viaggio verso nord-est abbiano via via incorporato scaglie del substrato (riconoscibili oggi per lo più come esotici) e masse di sedimenti freschi (per lo più passati nell'imballaggio argilloscistoso).

In secondo luogo, le dislocazioni dell'autoctono, cioè di ogni terreno toscano ad eccezione delle argille scagliose, sono sostanzialmente dovute non a pieghe bensì a faglie. Migliorini ha mostrato (1940) in una comunicazione precedente a questa che sistemi di faglie normali e inverse possono determinare sollevamenti, purché i piani di faglia convergano in basso. Questi sollevamenti, succedutisi dall'interno all'esterno dell'arco appenninico, fornirono i pendii su cui ebbero luogo i fenomeni di cedimento gravitativo (" frane orogeniche " di Migliorini). Da questo punto di vista l'interesse principale si accentra sulle dislocazioni dell'autoctono, non essendo gli spostamenti della coltre alloctona, per quanto cospicui, che delle conseguenze di quelle. Migliorini ha tratto dall'Appennino meridionale le principali prove di fatto a sostegno della sua teoria dei " cunei composti," e ne ha previsto la generale applicabilità. Le osservazioni che seguono hanno appunto l'intento di dare le prove della validità dello schema tettonico di Migliorini nell'Appennino settentrionale.

Una catena di strutture è stata seguita dal Passo del Cerreto fino al Monte di Cetona, per una lunghezza di più di 200 km. Singole unità di questo allineamento sono le strutture del Cerreto, Mommio, Soraggio (Azzaroli), Pania di Corfino (Trevisan), Val di Lima, Montecatini-Monsummano (Azzaroli), Monte Albano (Azzaroli, Losacco), Chianti (Valduga), Rapolano (Losacco), Cetona (Merla). In corrispondenza di ciascuna struttura (tranne al Monte Albano, il cui termine stratigrafico più basso è il macigno) calcari mesozoici affiorano di sotto alle argille scagliose, o all'arenaria macigno del Terziario medio; e faglie normali immergenti a sud-ovest si osservano sul tergo.

Nell'area del Passo del Cerreto, Azzaroli ha rintracciato sia le faglie normali sul tergo, sia almeno una faglia inversa sul davanti della struttura. La faglia inversa immerge a sud-ovest come quelle normali ma più debolmente (come è richiesto dallo schema dei cunei composti); e può essere seguita per una decina di km. Il passo propriamente detto è una stretta incisione, a margini più o meno rettilinei, attraverso la cresta principale dell'Appennino reggiano. In corrispondenza dell'incisione il

macigno è assente, per quanto sia normalmente sviluppato subito a sud-ovest e a nord-est del passo con uno spessore di almeno 1500 m. Nel solco del passo, invece, lembi di rocce alloctone ricoprono immediateamente una scaglia profondamente arricciata e mescolata a gessi, calcari dolomitici e quarziti del Trias superiore. L'erosione non è la causa di questa locale e improvvisa mancanza di macigno. A nord-est, proprio di fronte all'incisione ove il macigno è assente, diverse placche di questa formazione ricoprono le argille scagliose invece di esserne, come di regola, ricoperte. Si presenta quindi naturale la conclusione che il macigno che non troviamo più in posto al Passo del Cerreto è scivolato pochi km a nord-est, e va oggi cercato al Monte Ventasso. Già Anelli aveva proposto questa spiegazione fin dal 1935 (Anelli, 1935). In seguito alla diminuzione di carico derivante dallo scivolar via del macigno, le formazioni inferiori a questo sono state sospinte in alto lungo la cicatrice lasciata dal macigno, trascinando con sè brandelli di quarziti e di rocce cristalline. Questo movimento è stato certo assai facilitato dalla presenza di gessi. Al tempo stesso, del materiale alloctono affluiva nella cicatrice da tergo, venendo così in contatto con rocce da cui, di regola, è separato dal macigno.

Dalla cresta dei lembi sollevati lungo le faglie inverse, i quali sono stati spinti entro la massa delle argille scagliose sormontandone una parte, si staccano blocchi di calcari gessosi e dolomitici, che passano a far parte della coltre alloctona franando con questa a nord-est. E' un esempio, piuttosto raro, di blocchi esotici in statu nascendi.

Senza eccezione, tutte le altre strutture che si succedono lungo l'unità tettonica principale di cui ci stiamo occupando mostrano colla massima chiarezza le faglie normali sul tergo. Esempi cospicui sono forniti dalla Pania di Corfino (Trevisan, 1946) e dalla Val di Lima (Masini, 1932). L'affioramento mesozoico di Monsummano, come dimostra Azzaroli (1948), è un piccolo cuneo di calcari e diaspri giuresi limitato a sud-ovest da un sistema di faglie normali e da una faglia inversa a nord-est. Lungo la faglia normale principale sgorgano sorgenti termali connesse con le famose acque minerali di Montecatini. Si può anzi affermare come regola valida per l'intera Toscana che le sorgenti termo-minerali sono connesse con le faglie normali dei cunei strutturali; e varrebbe forse la pena di ricercare se questa regola valga anche per i " soffioni " (sorgenti di vapore surriscaldato) della Maremma. Va aggiunto subito che la dipendenza delle sorgenti termo-minerali dalle faglie fu certo stabilita in un tempo assai più recente del primo insorgere dei cunei strutturali. Le sorgenti, come fanno pensare i travertini associati, hanno cominciato a sgorgare di massima nel Quaternario, durante dislocazioni tardive che rimisero in giuoco le vecchie fratture, e probabilmente sotto un regime in prevalenza di distensione.

Nella struttura del Chianti si osservano di nuovo le faglie normali. Sul pendio esterno (cioè verso l'Adriatico) della struttura, Valduga (1948) ha osservato nel macigno esempi assai interessanti di dislocazioni per cedimento gravitativo. " Flaps " di macigno (per il termine, vedi Harrison e Falcon, 1936) delimitati sul tergo, cioè a sud-ovest, da faglie longitudinali e dalle parti da faglie trasversali, ribaltano a nord-est nel senso di franamento del loro imballaggio argilloscistoso che li preserva da un totale sbriciolamento. Al tempo stesso il sovraccarico locale derivante dal ribaltamento fa sì che il flap sprofondi lungo una faglia longitudinale, andandosi ad incassare fra porzioni di macigno non ribaltato. La struttura che ne risulta, piuttosto paradossale, potrebbe definirsi una " pseudo-anticlinale." I lembi ribaltati ora descritti ricordano da vicino quelli resi noti nella Persia da Harrison e Falcon, con una differenza significativa: i flaps appenninici, anche se di modeste dimensioni, sono ordinariamente sprofondati. Ciò può essere spiegato ricordando che i flaps dell'Appennino sono tipicamente strutture sinorogeniche, cioè formatesi in un campo di energici sforzi tettonici accompagnati da un'estesa fratturazione delle rocce, tanto che i vari elementi della litosfera non vi dovettero avere una gran resistenza al carico. L'esempio di questi flaps del Chianti congiuntamente all'altro della risalita di rocce al Passo del Cerreto mostra che nell'Appennino la litosfera si è comportata come una bilancia bene equilibrata, assai sensibile alle variazioni di carico.

Nella zona del Pratomagno-Consuma, che peraltro appartiene ad un'altra struttura principale successiva e sub-parallela a quella Cerreto-Cetona, sono chiaramente visibili le faglie sia normali che inverse di una struttura a cuneo debolmente immersa a sud-ovest (ricerche dello scrivente, 1948).

Finalmente, anche la struttura mesozoica del Monte di Cetona, per quanto annegata sotto depositi trasgressivi del Pliocene, mostra sul tergo un complicato sistema di faglie direzionali normali, accompagnate come al solito da sorgenti termali. La serie stratigrafica del pendio anteriore non contiene macigno, che è al contrario ben sviluppato sul tergo della struttura. Sul pendio anteriore manca anche la scaglia, e le argille scagliose alloctone vengono ivi in contatto con i diaspri del Giurese. Sembra assai probabile che vi sia stata denudazione tettonica, per essere il macigno e la scaglia scivolati via sotto l'azione della gravità. Di fatto, fette e blocchi di scaglia e macigno sono comuni nelle argille scagliose ad oriente del Cetona (ricerche dello scrivente, 1947–48).

Diamo ora un'occhiata ad una buona carta fisiografica della Toscana, per es. al 250.000 recentemente edito dall'Istituto Geografico Militare di Firenze. La struttura ora descritta, che si stende dalle montagne della Liguria fino al territorio vulcanico della Campagna Romana, è certamente una unità tettonica di prim'ordine dell'Appennino settentrionale. Altre strutture consimili esistono, per quanto la loro estensione non sia stata ancora determinata. In attesa di ulteriori risultati tettonici, queste strutture principali possono essere argomentate osservando le caratteristiche oro-idrografiche. Per esempio, è facile notare che nel tratto centrale dell'Appennino settentrionale le catene minori e gli affluenti dell'Arno vanno da nord-ovest a sud-est secondo la direzione appenninica normale. Dal Tirreno verso l'Adriatico, si possono contare le seguenti strutture principali. Prima, la struttura dei Monti Livornesi; seconda, la struttura Bagni di Casciana-Orciatico; terza, la struttura Jano-Montagnola Senese. La struttura del Chianti, che è parte dell'unità tettonica principale Cerreto-Cetona, è la quarta. Viene poi la quinta struttura, quella del Pratomagno-Consuma. Sesta è la struttura del Monte Falterona.

Secondo quanto oggi sappiamo, l'ipotesi che il sollevamento di ciascuna struttura sia avvenuto secondo lo schema dei cunei composti di Migliorini sembra aver superato con successo le prime verifiche sul terreno. Certo, i cunei strutturali dell'Appennino settentrionale non sono così evidenti e completi come quelli dell'Appennino meridionale. Specialmente la documentazione delle faglie inverse anteriori non è abbondante, mentre le faglie normali sul tergo sono dovunque osservabili. In riassunto, vanno ricordati i seguenti argomenti in favore dei sollevamenti a cuneo nell'Appennino settentrionale.

(i) La tettonica rilevabile delle unità strutturali si discosta affatto da ogni possibile schema a pieghe. Le faglie hanno la parte principale. Le faglie normali sono di regola situate sul tergo delle strutture, cioè precisamente dove lo schema dei cunei composti richiede che ve ne siano.

(ii) Alcuni sistemi di faglie normali ed inverse convergenti in basso sono stati di fatto osservati (Passo del Cerreto, Montecatini-Monsummano, Pratomagno-Consuma).

(iii) Il pendio anteriore delle strutture è il più largo. La formazione di scaglie di rocce del substrato e gli slittamenti per gravità si verificano principalmente sul pendio anteriore delle strutture, come prevede lo schema dei cunei composti.

Vi sono inoltre buone ragioni per aspettarsi che le caratteristiche in superficie dei cunei debbano essere meno evidenti nell'Appennino settentrionale che in quello meridionale. Per la loro stessa conformazione, le faglie inverse sono soggette a un rapido smantellamento, e ciò è tanto più vero quando, come nell'Appennino settentrionale, siano diffusi i materiali plastici superficiali. Infatti nell'Appennino settentrionale la piastra rigida che si rompe e si solleva a cuneo sotto gli sforzi di compressione non raggiunge la superficie, e gli sforzi di taglio risultanti vengono ad essere annullati nella sovrastante porzione della crosta, formata dagli argilloscisti della scaglia e dall'arenaria macigno, quest'ultima ancora semi-plastica al tempo delle deformazioni orogeniche.

Al di sopra delle strutture dell'autoctono, si stendono argille scagliose caotiche di provenienza occidentale, talora con enormi spessori, altrove molto sottili o assenti fin dall'inizio. L'entità dello spostamento delle argille scagliose verso nord-est è imponente: verso il margine padano esse contengono singole masse rocciose che hanno viaggiato per più di 150 km.

Qualora si voglia supporre che le intumescenze dell'autoctono si siano sollevate più o meno contemporaneamente nella larghezza dell'Appennino, allora l'enorme traslazione delle argille scagliose resterebbe un insoluto problema meccanico. Al contrario, si intuisce immediatamente la possibilità

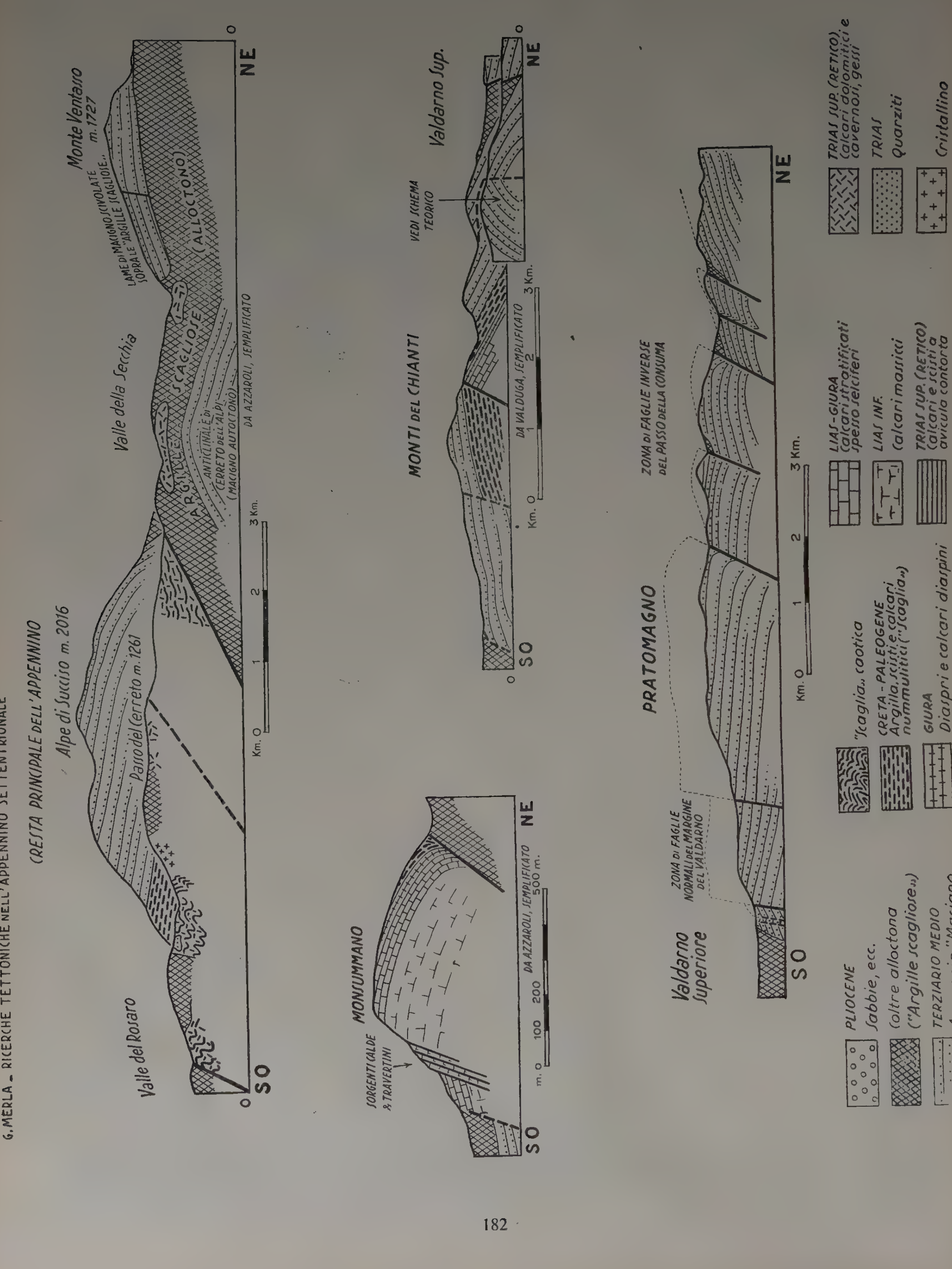
G. MERLA _ RICERCHE TETTONICHE NELL'APPENNINO SETTENTRIONALE
CRESTA PRINCIPALE DELL'APPENNINO
Alpe di Succiso m. 2016
Monte Ventasso m. 1727
Valle del Rosaro
Passo del Cerreto m. 1261
Valle della Secchia
LAME DI MACIGNO SCIVOLATE SOPRA LE "ARGILLE SCAGLIOSE"
ARGILLE SCAGLIOSE (ALLOCTONO)
ANTICLINALE DI CERRETO DELL'ALPI (MACIGNO AUTOCTONO)
DA AZZAROLI, SEMPLIFICATO
SO
NE
Km. 0 1 2 3 Km.
MONSUMMANO
SORGENTI CALDE & TRAVERTINI
DA AZZAROLI, SEMPLIFICATO
m. 0 100 200 500 m.
MONTI DEL CHIANTI
Valdarno Sup.
VEDI SCHEMA TEORICO
DA VALDUGA, SEMPLIFICATO
Km. 0 1 2 3 Km.
PRATOMAGNO
Valdarno Superiore
ZONA DI FAGLIE NORMALI DEL MARGINE DEL VALDARNO
ZONA DI FAGLIE INVERSE DEL PASSO DELLA CONSUMA
Km. 0 1 2 3 Km.
PLIOCENE Sabbie, ecc.
(oltre alloctona ("Argille scagliose")
TERZIARIO MEDIO Arenaria "Macigno"
"Scaglia" caotica
CRETA - PALEOGENE Argilla, scisti e calcari nummulitici ("Scaglia")
GIURA Diaspri e calcari diaspini
LIAS-GIURA (calcari stratificati spesso selciferi
LIAS INF. Calcari massicci
TRIAS SUP. (RETICO) (calcari e scisti a avicula contorta
TRIAS SUP. (RETICO) (calcari dolomitici e cavernosi, gessi
TRIAS Quarziti
Cristallino

FIG. 1.

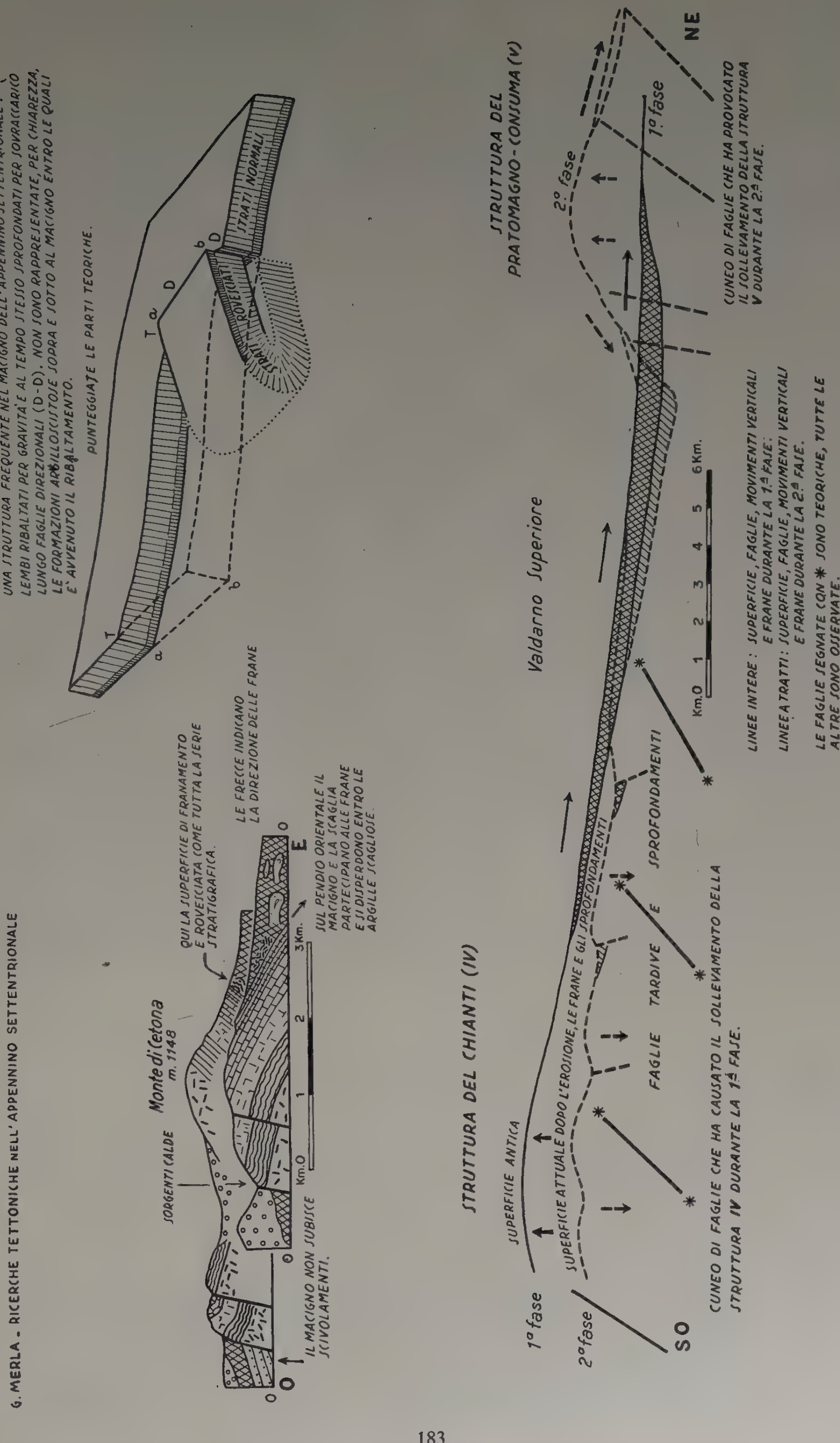
G. MERLA - RICERCHE TETTONICHE NELL' APPENNINO SETTENTRIONALE
UNA STRUTTURA FREQUENTE NEL MACIGNO DELL'APPENNINO SETTENTRIONALE: LEMBI RIBALTATI PER GRAVITÀ E AL TEMPO STESSO SPROFONDATI PER SOVRACCARICO LUNGO FAGLIE DIREZIONALI (D-D). NON SONO RAPPRESENTATE, PER CHIAREZZA, LE FORMAZIONI ARGILLOSCISTOSE SOPRA E SOTTO AL MACIGNO ENTRO LE QUALI È AVVENUTO IL RIBALTAMENTO.
PUNTEGGIATE LE PARTI TEORICHE.
STRATI NORMALI
STRATI ROVESCIATI
Monte di Cetona m. 1148
SORGENTI CALDE
QUI LA SUPERFICIE DI FRANAMENTO E ROVESCIATA COME TUTTA LA SERIE STRATIGRAFICA.
LE FRECCE INDICANO LA DIREZIONE DELLE FRANE
IL MACIGNO NON SUBISCE SCIVOLAMENTI.
SUL PENDIO ORIENTALE IL MACIGNO E LA SCAGLIA PARTECIPANO ALLE FRANE E SI DISPERDONO ENTRO LE ARGILLE SCAGLIOSE.
O
E
Km. 0 1 2 3 Km.
STRUTTURA DEL CHIANTI (IV)
Valdarno Superiore
STRUTTURA DEL PRATOMAGNO-CONSUMA (V)
1° fase
2° fase
SO
NE
SUPERFICIE ANTICA
SUPERFICIE ATTUALE DOPO L'EROSIONE, LE FRANE E GLI SPROFONDAMENTI
FAGLIE TARDIVE E SPROFONDAMENTI
CUNEO DI FAGLIE CHE HA CAUSATO IL SOLLEVAMENTO DELLA STRUTTURA IV DURANTE LA 1ª FASE.
CUNEO DI FAGLIE CHE HA PROVOCATO IL SOLLEVAMENTO DELLA STRUTTURA V DURANTE LA 2ª FASE.
Km. 0 1 2 3 4 5 6 Km.
LINEE INTERE: SUPERFICIE, FAGLIE, MOVIMENTI VERTICALI E FRANE DURANTE LA 1ª FASE;
LINEE A TRATTI: SUPERFICIE, FAGLIE, MOVIMENTI VERTICALI E FRANE DURANTE LA 2ª FASE.
LE FAGLIE SEGNATE CON ✱ SONO TEORICHE, TUTTE LE ALTRE SONO OSSERVATE.

FIG. 2.

di una soluzione ove si ammetta, con Migliorini e altri geologi italiani, che la successione verso nord-est delle singole unità strutturali segni anche la loro successione nel tempo. Secondo questo punto di vista, il sorgere di ogni intumescenza nel substrato ha fatto franare le argille scagliose, scaricandole di un'altra tappa a nord-est.

Così, le singole unità tettoniche principali che abbiamo enumerato non sono probabilmente contemporanee. E neppure permangono indefinitamente. Paragonate alle strutture nord-orientali, quelle di sud-ovest, più interne rispetto all'arco appenninico, non sono oggi più che rottami tettonici. Il loro abbassamento ritengo non sia dovuto semplicemente a degradazione superficiale, ma anche a veri e propri sprofondamenti. Limitandoci a confrontare fra loro diversi tratti della quarta struttura principale (Cerreto-Cetona) vediamo infatti che un determinato livello stratigrafico, per esempio la base del macigno, si incontra a q.1200 nella zona di Passo del Cerreto e a q. 300 e anche più in basso nel Chianti, ove anche la quota media delle cime è corrispondentemente più bassa. Se questa minore altezza delle cime fosse da ascriversi soltanto ad erosione più intensa, allora l'aggiustamento isostatico (che è più che ragionevole debba seguire in una regione da cui si suppone asportata una coltre rocciosa spessa intorno a un km) avrebbe fatto risalire più in alto la colonna stratigrafica nella regione più erosa, cioè, per ipotesi, nel Chianti; e il livello stratigrafico di riferimento, supponendosi assenti movementi tettonici di sprofondamento, si dovrebbe trovare oggi all'altezza dove l'aggiustamento isostatico lo avesse sospinto: il che è in palese contrasto con l'osservazione. Se poi si volesse ammettere un iniziale minor sollevamento nel tratto chiantigiano della struttura, si urterebbe in un'altra difficoltà, in quanto i fenomeni di degradazione e demolizione dall'alto (erosione, frane tettoniche, subordinatamente flaps) non sono certo meno sviluppati nel Chianti che nella zona del Passo del Cerreto: ciò che richiede pendii originarii, cioè sollevamenti, dello stesso ordine di grandezza nelle due regioni. In linea di fatto, nella struttura del Chianti sono state osservate faglie immergenti a nord-est (Merla, Valduga), cioè indipendenti dalle faglie del cuneo con immersione a sud-ovest che avrebbero provocato il sollevamento. Queste faglie supplementari potrebbero precisamente essere dovute allo sprofondamento, rispetto a ciascuna di esse ancora in regime di compressione, del tratto di sud-ovest.

I vari argomenti esposti concorrono nel suggerire che una fase finale di sprofondamento sia un evento normale nell'evoluzione di molte strutture appenniniche. I pendii di franamento orogenico sarebbero dunque labili, ciascuno destinato ad essere sostituito da uno successivo più a nord-est.

In questo ordine di idee, le presenti sommarie osservazioni sulla tettonica dell'Appennino si possono convenientemente concludere citando la vivida immagine usata nel 1932 da E. B. Bailey (1932) per rappresentare le vecchie idee di Schardt sul movimento dei klippen alpini. Applicando le parole di Bailey alle frane di argille scagliose nell'orogenesi appenninica, queste si potrebbero paragonare a un " surf-rider, mounted on his board, and skilfully gliding down the forward slope of an advancing wave."

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COMPOSITE WEDGES AND OROGENIC LANDSLIPS IN THE APENNINES

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ABSTRACT

Recent research is showing that the structure of the Apennines departs widely from usually accepted patterns and is prevailingly the outcome of compressional faulting and orogenic landslipping. There are no true nappes, and folding plays only a subordinate part; crustal shortening is very moderate.

The individual Apennine ranges were uplifted successively, starting on the inner side of the mountain arc and moving outwards. Each one corresponds to a system of faults converging downwards and forming an uplifted composite wedge implying contraction.

The highly incompetent allochthonous formation covering extensive areas of the Apennines and known as *Argille scagliose*, Ligurid nappe, or Ophiolitic formation, cannot have advanced as a nappe, and is best accounted for by the successive landslip theory; that is by a succession of orogenic landslips down the outer slopes of the individual Apennine ranges, each landslip spreading sufficiently outwards to be picked up and moved forward, together with any freshly deposited unconsolidated deposits, by similar landslips on the outer slope of the next range to be uplifted.

There is no reason to suppose that these tectonic and orogenic features should be peculiar to the Apennines.

INTRODUCTION

WORK carried out by Italian geologists in recent years has shown that the structure and the geological history of the Apennines does not fall in with conventional tectonic and orogenic schemes, and new lines of approach have been attempted with good results.

The new concepts arrived at may be of considerable general interest, as there are reasons for believing that they may prove to be of widespread applicability.

The study of the Apennines has led to these new concepts not because this mountain system is in any way aberrant or exceptional, but because its orogenic development was comparatively simple and so recent that much of its synorogenic sedimentary mantle is still intact.

To keep the paper within a limited compass a rather abridged treatment has been necessary and much of the field evidence has had to be omitted. A fuller discussion of the subject is now being printed in the Bulletin of the Italian Geological Society (Migliorini, 1948).

SOME SALIENT FEATURES OF APENNINE STRUCTURE AND GEOLOGICAL HISTORY

(*a*) *The outward spread and the age of the mountain-building*

The approximately parallel ranges that make up the Apennines were formed successively, starting from the inside of the mountain arc: i.e., from the Tyrrhenian slope.

The innermost and oldest ranges are now foundered in the Tyrrhenian Sea, but their disrupted remnants abound in the Apennine allochthon.

Apennine mountain-building began in the Upper Cretaceous, with the Palaeoapennine phase (Migliorini, 1947b); this only affected the innermost ranges that are now foundered in the Tyrrhenian.

This phase was followed by a lull throughout the Eocene and part of the Oligocene.

In the Oligocene a second phase, the Etruscan set in and continued with varying intensity up to the early Pleistocene. In this phase the present Apennines were formed.

(*b*) *The Apennine autochthon*

Pre-orogenic formations—i.e., older than the Upper Cretaceous—need not be considered.

Over the area of the present Apennine arc sedimention during the Palaeoapennine phase and the following lull was not of orogenic facies.

Over the northern section of the arc an argillaceous and calcareous mudstone series known as *scaglia* was slowly deposited until the commencement of the Etruscan phase; then heavy orogenic sedimentation suddenly set in, and a thick clastic series, largely consisting of a sandstone and mudstone alternation known as *macigno*, was laid down conformably on the *scaglia*.

From pre-orogenic times extensive banks, mainly consisting of reef limestones, occupied large areas in the southern section of the Apennine geosynclinal trough. Organic accretion persisted over these until they were smothered by *macigno* or similar orogenic sedimentation in the latter half of the Etruscan phase.

(*c*) *The Apennine allochthon*

The only extensive rock-masses that do not occur in their proper stratigraphical position in the Apennine synorogenic sequence are the *argille scagliose*.

The *argille scagliose*, also known as Ophiolitic Formation or Ligurid Nappe, are a jumble of different varieties of shaly formations containing numerous exotics of all sizes, the whole being kneaded into a chaotic mass with no structural continuity. Taken as a whole, it is an extremely incompetent formation much given to landslips.

Among the exotics, sedimentary, metamorphic and igneous rocks occur. In the shaly matrix widely divergent geological ages are represented, ranging, in the northern Apennines, from the Cretaceous, and perhaps the Jurassic, to the Upper Tertiary.

The *argille scagliose* are not a nappe in the proper acceptation of the term. All the evidence bearing out this statement cannot be fully set out here, and two main arguments will have to suffice.

(i) The *argille scagliose* were never over-ridden and disrupted by a higher nappe. Accordingly, if they were thrust forward as a nappe, when this occurred they must have been in much the same condition that they are in to-day; and it is inconceivable that such a plastic sheet of disrupted material could be thrust forward from the rear over an uneven surface—especially since it could not have been more than some 2 km. thick at the outside, and in places must have advanced at least 200 km.

(ii) On the Adriatic slope of the Apennines the *argille scagliose* often overlie Tortonian, Pontian, and even Pliocene formations. But over extensive areas of the Tyrrhenian slope over which the nappe should have travelled, the *argille scagliose* had already been removed by Tortonian and in places even by Helvetian times; so that by then the propagation of any thrust from the rear would have been quite impossible.

COMPOSITE WEDGES

(*a*) *The structure of the calcareous Apennines*

In the area of the geosynclinal trough corresponding to the Apennines of the Latium and Abruzzi regions east of Rome, an extensive calcareous bank, largely formed by organic accretion, had existed since Triassic times. In this area, therefore, a rigid limestone sequence extends down to the Trias, and is capped only by Helvetian-Tortonian and Pontian clastics of no very great thickness, which have been removed over wide areas.

The structure of these rigid calcareous Apennines has been worked out by Beneo (Beneo, 1938a and b, 1939a, b, and c, 1940, 1943a, b, and c), and has been found to be dominated by faults striking parallel to the local Apennine trend and so arranged that each individual range, of which there are four, corresponds to a " horst."

Beneo gives a detailed cross-section of the Montagna del Morrone range (Beneo, 1939a), corresponding to the easternmost horst. From this Fig. 1 is taken, where it may be seen that the structure consists of a series of uplifted wedges, limited by faults that tend to converge in depth. Similar structures have been named by the writer composite wedges (*cunei composti*) (Migliorini, 1947d).

By analysing another section by Beneo crossing the whole Apennine arc from the neighbourhood of Rome to Pescara on the Adriatic coast (Beneo, 1939b), it is seen that the other three ranges of this stretch of the Apennines are also formed by composite wedges.

Other composite wedges occur in the calcareous Apennines of southern Italy, and also where the rigid pre-orogenic rocks outcrop through the mantle of orogenic clastics spreading over the northern Apennines.

(*b*) *The main features of composite wedges*

The section of the Montagna del Morrone composite wedge shows that:

(i) all the component wedges, and hence the whole composite wedge also, lean north-eastward, so that the faults are normal on the inner (West) side, and reversed on the outer (East) side of the mountain arc;

FIG. 1.—*Triassic to Mid-Miocene limestones overlain by Upper Tertiary and Pleistocene clastics (in black).*

FIG. 2.

FIG. 3.

(ii) the less inclined fault limiting the highest component wedge hades about 45°, and consequently the inner (West) slope of the composite wedge is steeper than the outer (East).

These features are common to all Apennine composite wedges.

Such an arrangement is given by the expression

$$h = H \sin 2\delta$$

where H is the maximum uplift of the composite wedge, h the uplift of the component wedge considered, and δ the dip of its less inclined limiting fault.

The above expression is admittedly empirical, no analysis of the mechanics of composite wedges having yet been attempted. It leads, however, to an arrangement strikingly similar to those actually observed, as may be seen by comparing Figs. 1 and 2. The main difference between the two sections is due to the pronounced drag-folding that accompanied the Montagna del Morrone overthrusting owing to the plasticity of the upper limestone members during the early phases of the deformation.

(c) *Origin of composite wedges*

Theoretically, composite wedges could be produced either by (1) compression only or by (2) compression and distension.

In a composite wedge normal faults besides reversed ones can be brought about by compression. A single normal fault necessarily implies distension; but if on its upthrow side it is followed by a reversed fault having a flatter hade, an inclined wedge is formed, whose uplift implies contraction and therefore compression (Fig. 3). The same reasoning applies to composite wedges.

Several arguments are strongly in favour of the first of the two hypotheses set out in the preceding paragraph:

(i) In the normal faults of all composite wedges of the calcareous Apennines, slickensiding and mylonitization are very pronounced; while in true distensional faults these features are absent or very poorly developed.

(ii) The distribution of marine Pliocene and lacustrine Villafranchian deposits upon and around the Monti della Maddalena (about 120 km. S.E. of Naples) shows that in the composite wedge forming this range normal and reversed faulting must have been almost, if not quite, contemporaneous (Migliorini, 1947d).

(iii) If not compressional, the normal faults of composite wedges would imply actual expansion and not mere crustal sagging, so that a contraction followed or preceded by an expansion would be needed for every composite wedge; and since it is known that the individual Apennine ranges were not formed simultaneously, a whole sequence of alternating distensions and compressions would be implied. Failure to these stresses, moreover, would always have had to take place along alternating parallel lines.

(iv) The areas corresponding to the composite wedges of the calcareous Apennines are highly seismic (Baratta, 1936), and earthquakes occur both on the normally faulted and on the overthrust sides, sometimes simultaneously. If these earthquakes are interpreted as evidence that faulting has not yet quite ceased—as seems only reasonable—the hypothesis that the composite wedges were formed by compression and distension would imply corresponding crustal contractions and expansions alternatively following each other at a pace that is quite out of keeping with the usually accepted views on the viscosity of the asthenosphere.

Though the above arguments are not strictly probative, their cumulative weight would appear to justify the acceptance of the hypothesis that composite wedges were formed by compression only.

What causes composite wedges to lean towards the outside of the Apennine mountain arc has not been investigated analytically. In a general way it should be connected with a rotative tendency brought about by the outward slope of the surface of the rigid zone underlying the imperfectly consolidated sediments freshly laid down along the belts that were compressed and uplifted as composite wedges.

(d) *Continuous composite wedges*

It will be useful to consider a theoretical composite wedge in which the fault surfaces are imagined to be true planes and so numerous as to render the cross-section of its upper surface a continuous curve. This theoretical structure may be called a continuous composite wedge.

It can be shown that the cross-section of the upper surface of a continuous composite wedge complying with the relation previously given is expressed by

$$x = (P + h)\,\frac{H \pm \sqrt{H^2 - h^2}}{h} - H \log \left[1 + \left(\frac{H \pm \sqrt{H^2 - h^2}}{h}\right)^2\right]$$

where P is the depth from the surface, before deformation, of the point F in which the traces of the fault planes on the cross-section converge, H is the maximum uplift of the composite wedge, and h

and x are respectively the ordinates and the abscissae of the curve referred to the point O situated vertically above F on the surface before deformation. $\sqrt{H^2 - h^2}$ is negative in the ascending arc and positive in the descending arc of the curve. F may be termed the focus, P the focal depth, H the height, and O the origin of the continuous composite wedge. If δ_1 and δ_2 are the dips of the two outer faults including the whole wedge, numbered from right to left, δ_1, δ_2 may be termed the sector of the continuous composite wedge.

The steep ascending arc of the curve nearest to the origin may be termed the near slope and the gentler descending one the far slope.

Fig. 4 represents the cross-section of a continuous composite wedge in which $P/H = 4$, $\delta_1 = 10°$, $\delta_2 = 90°$.

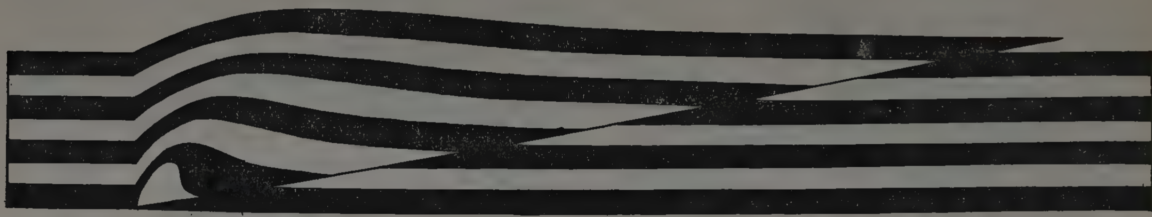

FIG. 4.

FIG. 5.

The equation of the continuous composite wedge rests on the relation given above (p. 189), which is empirical; but even if actual wedges were to follow some other law, this should not differ fundamentally from the one adopted, since the latter gives rise to a pattern closely resembling that occurring in nature.

The structure shown in Fig. 4 is not brought about by plastic deformation, but by very numerous and closely spaced faults. The structure shown in Fig. 5 is obviously the outcome of faulting, and if the faults shown in it were increased indefinitely continuous curves like those of Fig. 4 would ensue.

It is not implied that composite wedges actually exist with faulting so closely and evenly spaced as to give rise to continuous composite wedges. The latter, however, may be taken as the shape to which actual composite wedges would tend statistically.

Moreover, if the material involved in the deformation were in part moderately plastic, the fault scarps in the resulting composite wedge would be smoothed over and the structure would approach the theoretical continuous pattern.

(e) *Properties of composite wedges*

The crustal contraction implied by a continuous composite wedge can be calculated if H, δ_1, and δ_2 are known.

In composite wedges having a finite number of faults like those occurring in nature, the shortening will be less for equal values of H, δ_1 and δ_2.

A composite wedge can arise only if the thickness of the rigid layer contained in it is less than the focal depth. Its focus, in other words, must fall in an underlying plastic zone; either below the zone of fracture or in some incompetent layer.

Moreover, deformation by displacement along the fault system of a composite wedge will cease and the latter will close when the unfaulted portions meet at the bottom of the rigid layer. One can calculate what height a continuous composite wedge will have to attain for this to occur when its focal depth and sector and the thickness of the rigid layer are known. In composite wedges actually occurring in nature, a greater height can be attained before closure occurs, other conditions being the same.

If orogenic compression continues with sufficient intensity after the closure of a composite wedge, crustal contraction will occur along the next weakest belt. It appears reasonable to suppose that at first this may still correspond with the line where the closure occurred, and that here deformation will take place by the formation of new faults not forming part of the system of the original composite wedge. But eventually this superimposed system of faults will also close, and the zone of failure will shift to some other parallel belt, where a new composite wedge will arise.

Observational data (see p. 195) and theoretical considerations agree in indicating that the new composite wedge should usually thus arise along a belt lying parallel to the definitely closed one on the outer margin of the mountain arc.

COMPOSITE WEDGES, OROGENIC LANDSLIPS AND ISOSTASY

(a) *Orogenic landslips and the successive landslip theory*

When a slope becomes steeper than the angle of repose of the material forming it, landslipping necessarily ensues. In ordinary landslips and submarine slumps the steepening is brought about by erosion on dry land, and by the seaward decrease of the rate of sedimentation on the sea-floor (Migliorini, 1944).

During orogenesis, landslips must set in as a direct effect of crustal deformation whenever the latter gives rise to steep enough slopes. At the same time the agents responsible for ordinary landslips will become more effective owing to the increased rates of erosion and sedimentation brought about by rejuvenation. Deformation, moreover, will often take place in coastal areas where the superficial layers are still more or less unconsolidated and have a low angle of repose. The very large landslips that these conditions will concur in bringing about have been called by the writer orogenic landslips (*frane orogeniche*) (Migliorini, 1933).

In mountain ranges built up, like the Apennines, of parallel ridges successively added on to the outside of the arc, the landslips moving inward cannot travel far, since they are soon held up by the precedingly formed ridge; but on the opposite slope they will find no obstruction and may well spread their disrupted material down the slope bordering the forelying geosynclinal trough, which would be the very area in which the next ridge would arise. Thus the latter, when it arose, would be capped by disrupted material derived from the preceding landslips, which would slip together with the more recent poorly consolidated sediments when the ridge became pronounced enough.

This process would be repeated every time a new ridge arose on the outer side of a preceding one, the landslips ever increasing in size and their materials becoming more heterogeneous as the forward

drive of the allochthonous debris proceeded and as successively younger sediments were disrupted and engulfed by the landslips.

This mechanism may be termed the successive landslip theory.*

Rocks subjected to the displacements implied by the successive landslip theory could well acquire the disjointed and chaotic features of the *argille scagliose*; and the very incompetence and discontinuity of the Apennine allochthon which are against its being interpreted as a true nappe, become just what one should expect with this theory.

In recent years field evidence of sliding and of actual landslips has been recorded within both the allochthon (Merla, 1933; Beneo, 1945; Migliorini, 1947b; Losacco, 1947) and the autochthon (Migliorini, 1947a; Beets, 1946) of the Apennines.

(*c*) *Composite wedges and the successive landslip theory*

The successive landslip theory does not demand that the ridges giving rise to the landslips should necessarily be due to composite wedges; but with these the slopes on the outside of the mountain arc are the longest, while according to conventional reconstructions the opposite usually occurs with ridges formed by folding, so that with the former more material would slip successively towards the outside of the mountain arc than with the latter.

Composite wedges, moreover, afford an explanation of certain peculiar features of the Apennine allochthon that otherwise are hard to account for. Here it will be possible to outline briefly only a few of these features relating to the exotics engulfed in the *argille scagliose*.

The largest of these exotics are usually comparatively undisturbed raft-like masses of calcareous and marly mudstone or of sandstone, sometimes measuring several square km. Similar large slabs could become detached and slide downwards as soon as the support of the upper layers was removed by the overthrusting at the foot of the far slopes of composite wedges (see Fig. 4). This mechanism would be the very one advocated by Baldry and by Barrington Brown to account for the very large-scale slipping in the Tertiary of Peru (Baldry, 1938) and Ecuador (Brown, 1938). It should be added that slip-planes identical with those described by these authors are met with in the Apennines (Migliorini, 1947a).

In some instances the strata of the large flat exotics in question are overturned (Signorini, 1938). This might well be the effect of a combination of the process just outlined with the formation of flap-structures as described by Harrison and Falcon in Iran (Harrison and Falcon, 1936).

Various other types of exotics in addition to those dealt with so far occur in the *argille scagliose*. On the whole, these are smaller, not so flat and more broken up. As a rule they are derived from deeper layers.

Such exotics could have been added to the *argille scagliose* during the advanced stages of development of composite wedges, when the blades of rigid deep-seated rocks over the hanging wall of each overthrust on the far slopes would be forced into the overlying more incompetent mass and might well be broken off and become embedded in any ensuing landslip.

(*b*) *The effect of isostasy*

In a belt undergoing orogenic deformation isostatic adjustment may be considered to be practically immediate and effective over very small prisms. This assumption is justified by the speed that recent research in Fennoscandia has shown isostatic adjustment can attain, and by the consideration that orogenic and isostatic stresses must necessarily combine to form a vectorial field in the weak areas undergoing deformation.

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* On this theory allochthonous material could travel over long distances without there ever being any very considerable difference of elevation; while to obtain the same result with a single inclined surface this difference would often have to be enormous.

The general effect of isostatic adjustment will be to uplift the high areas from which landslips remove material and to depress the lower ones where they accumulate it. This will obviously delay the re-establishment of the angle of repose on the slopes and thus enhance landsliding.

(*c*) *Complete removal of the orogenic sedimentary mantle*

When the development of a composite wedge reaches a very advanced stage, its upper slopes tend to become precipitous (see lower layers in Fig. 4). In this condition all but the highly competent substratum would peel off and be carried away by landslips and the areas thus unloaded would rise isostatically for a substantial fraction of the thickness of the strata removed. In the Carrara Mountains, for instance, the complete removal of the orogenic clastic covering, which may be estimated to have been over 2,000 m. thick, must have brought about an isostatic uplift of the order of 1,500 m. at least. This should of course be added to the orogenic uplift of the composite wedge; while to compute the total relative tectonic uplift, the isostatic depression in the areas where the landslips accumulated should also be taken into account.

The group of wedges pushed up in the manner considered could only consist of very competent rocks, so that its uplift would be attended by faulting.

Fig. 6 is an attempt to represent the cross-section of the type of structure to which the above processes would lead.

The mechanism outlined explains satisfactorily the general structures of the Carrara Mountains, of other smaller pre-orogenic outcrops north of Lucca, and of similar occurrences on the Tyrrhenian slope of central Italy and in the Apennines of the Umbria and Marche regions (Ufficio Geologico d'Italia, 1931).

COMPOSITE WEDGES AND THE CONSISTENCY OF THE LITHOSPHERE

The thickness of the zone of fracture is not known with any certainty: it should vary considerably with the lithology and with the character of the orogenic stresses. From Griggs's and Goranson's researches (Goranson, 1940; Griggs, 1940) it would appear that under certain conditions plastic deformation could set in in rigid rocks (limestones) at a depth of about 7,500 m.

Rocks within the fracture zone may also react plastically if they are sufficiently incompetent.

In belts undergoing orogenic compression, the fracture zone may be made up of alternating rigid and plastic layers. In such cases the former will be shortened by fracture, and the latter by plastic deformation. During deformation, moreover, the mechanical properties of the rocks may undergo important changes: mudstones, which at the outset are rigid, will be promptly crushed into an incompetent mass reacting plastically; while sands and some calcareous muds will keep quite plastic until the equilibrium of their connate fluids is broken and they are cemented by circulating waters. Igneous and massive carbonate rocks, on the other hand, are rigid from the outset in the fracture zone, and can only attain a certain plasticity if very severely crushed.

From the above considerations it follows that the manner in which belts of heterogeneous fracture zone will deform varies with their composition, so that each one of such belts must be dealt with separately in reconstructing its deformation deductively.

COMPOSITE WEDGES IN THE CLASTIC APENNINES

Over the greater part of the northern Apennines the *macigno* has not been removed and the original plasticity of this largely arenaceous complex has prevented the formation of composite wedges like those seen in the calcareous Apennines.

Here a reconstruction according to the criteria outlined in the preceding paragraph has been attempted in the main Apennine range N.E. of the Casentino—the uppermost Arno basin N. of Arezzo—in Tuscany. The presumable vertical section in this area down to the zone of plastic deformation—which is assumed to commence at a depth of 8 km.—is represented in Fig. 7, in which the competent rocks are hatched and the incompetent ones are not, so as to show their change of consistency during orogenesis.

FIG. 6.—*Inclined arrows indicate direction of landsliding, and vertical arrows the ensuing isostatic displacement.*

From this figure it is seen that during the whole deformation the lower 2,700 m. of the fracture zone were constantly rigid, so that once a composite wedge got started it would continue to develop until closure. In the early stages this rigid substratum would have been still thicker (4,200 m.) and would have been overlain by an alternation of competent and incompetent rocks, the latter predominating and capping the section with a member 2,000 m. thick. In these conditions the faults of the underlying composite wedge could not reach the surface and would degenerate upwards into folds. The angle of repose of the superficial formations would be very low and landsliding would commence early on the steeper near slope.

As deformation progressed, the thick uppermost incompetent layer would gradually be cemented from the surface downwards by circulating waters as it rose above sea-level, and its angle of repose would increase greatly; but the steepening of the slopes would favour the slipping off of large slabs of the cemented crust.

At a still later phase the thickness of the upper cemented crust would increase to about 1,500 m., but it would still be separated from the deep-seated rigid layer by a section of well over 3,000 m. of alternating competent and incompetent layers, which would damp off the deep faults of the composite wedge and tend to smooth out the profile of the ridge. The cemented upper layer, being too rigid to fold, would be faulted, but these faults would not necessarily lie in continuation of those on the deep-seated composite wedge.

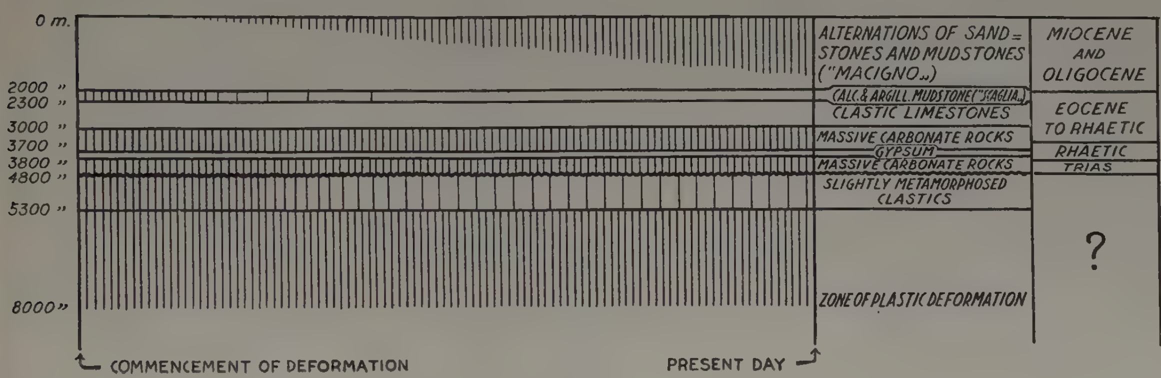

FIG. 7.

A considerable body of field data, too lengthy to set out here, bears out that the deformation of this section of the Apennines actually occurred as has been outlined.

The development of the deformation of this stretch of the main Apennine range would imply the smoothing out of the fault scarps of the deep-seated composite wedge and only moderate landsliding, especially on the far slope; so that the cross-section should not depart too widely from that of a continuous composite wedge.

In Fig. 8 the actual section across this Apennine range is compared with that of a continuous composite wedge having $P = 10$ km., $H = 16$ km., $\delta_1 = 13°$, $\delta_2 = 80°$. P is inferred from data drawn from the calcareous Apennines, while the other dimensions ensue from the local topographical and geological conditions.

The agreement between the cross-sections in Fig. 8 is striking, and the discrepancies between the two are what the moderate landslipping would lead one to expect. The crustal shortening implied by the continuous composite wedge is less than 4·2 km.

Similar tests have been applied to other sections of the Apennines further westward and north-westward, and the results have been the same. All the ranges considered are morphologically and geologically typical of the non-calcareous Apennines.

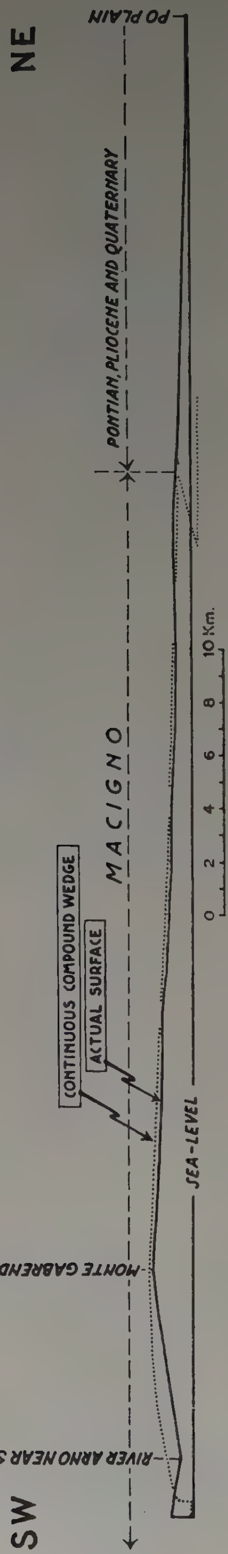
NE
PO PLAIN
PONTIAN, PLIOCENE AND QUATERNARY
MACIGNO
CONTINUOUS COMPOUND WEDGE
ACTUAL SURFACE
SEA-LEVEL
MONTE GABRENDO
RIVER ARNO NEAR STIA
SW
0 2 4 6 8 10 Km.

FIG. 8.

SUMMARY AND CONCLUDING REMARKS

(*a*) *Summary*

Composite wedges are the dominating structures in the calcareous Apennines and evidence is strongly in favour of their having a purely compressional origin.

The Apennine allochthon, whose features are incompatible with conventional nappe tectonics, is satisfactorily accounted for by the successive landslip theory.

By placing composite wedges and successive orogenic landslips in their proper isostatic setting, and by taking into due account the varying mechanical features of the lithosphere, a complex orogenic mechanism ensues which differs substantially from conventional ones.

(*c*) *Concluding remarks*

It is most improbable that the orogenic mechanism based on composite wedges and successive orogenic landslips to which the study of the Apennines leads, should be peculiar to this mountain system, since

(i) composite wedges should be the unavoidable effect of compression in a rigid medium, and the limestone sequences in which they are best displayed in the Apennines show no exceptional features;

(ii) the principles governing the successive landslip theory should by their nature be of general application, and formations having the same identical features as the *argille scagliose* are widespread: the writer has seen them in the Aegean islands, in Cyprus, in Asia Minor, and in the Carpathians. Probably the Cornish killas is a metamorphosed *argilla scagliosa.* Numerous other examples of similar formations could be quoted from geological literature if space permitted;

(iii) the other processes upon which the orogenic scheme hangs, such as isostasy and the cementation of clastic rocks by circulating waters, are obviously valid the world over.

It therefore seems justifiable to consider the possibility that the orogenic scheme that has been set out may prove to be more generally applicable, and to test its applicability outside the Apennines. And from this it follows that it is worth seeing what would be the main consequences of its application.

(i) Tectonic reconstructions would be deeply affected and the part played by erosion would be greatly reduced.

Compressive fault systems would oust folds as the dominant structures. Obviously this could not imply the non-recognition of the numberless folds that are actually observable; but such folds would be the effect in an originally plastic medium of deeper-seated compressional faulting. The concept that rocks bend only when they cannot transmit shear would supersede the one that rocks fracture when they can no longer bend.

(ii) Nappe tectonics in the fracture zone would be ruled out, thus eliminating the main argument in support of the enormous crustal contractions advocated for many mountain systems.

(iii) Crustal contractions would be very moderate. The present Apennine ranges, for instance, would nowhere be attended by a contraction exceeding some 15 km. at the outside.

This aspect of the subject might lead to a revision of the respective merits of the various hypotheses on the nature of mountain-building forces.

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DISCUSSION

E. B. BAILEY remarked on the interest long since aroused in the so-called Ligurid Nappe. He said that geologists would now, more than ever, want to go and see the evidence of the Apennines.

G. M. LEES said that he was unable to comment on the many major issues raised by the two papers on the Apennines though he was surprised to learn that the existence of major overthrusts was now being questioned. On matters of detail, he wished to record his disagreement with the comparison between the examples described and the gravity collapse structures of Persia. It did not seem possible for the gently dipping sandstone to fold back on itself by the influence of gravity in the way shown on the section, and, even if it did, it seemed unreasonable to suppose that the extra load would cause normal faulting. The conception of isostasy was, he thought, in that and in other instances in the papers, misused. Isostasy was a convenient and facile phrase, but he did not believe in it as an active principle, and thought that such frequent appeal to it distracted attention from the more fundamental principles of mountain building.

C. I. MIGLIORINI, in reply to Dr. Lees, said that in the tectonic features of the Appennines that had been compared with the gravity collapse structures of Persia, the *macigno* appeared to have been bent over by the weight of the stratigraphically underlying *scaglia* where the latter was piled up at the foot of steep tectonic slopes. This would appear to be the very mechanism advocated for the Persian examples. In dealing with the Appennines the matter had been treated so summarily that this point of resemblance had not been brought out clearly.

As to the acceptability of isostasy, it was a question that needed a lot of discussion to thrash out adequately. In the mountain building mechanism suggested for the Appennines, however, only a rather special and limited aspect of isostasy was brought into play as an accessory agent.

A NEW OROGENIC EPOCH IN THE PRE-CAMBRIAN OF GREENLAND

By A. NOE-NYGAARD

Denmark

ABSTRACT

The Geological Survey of Greenland (established in 1945) has worked out a reconnaissance map of the region between 66° and 69° N. lat. in West Greenland. Two old chains of folded mountains have here been recognized, separated by a period of widening and dyke injection.

The older chain, designated the "Kangamiut complex," is likely to belong to the "Ketilidian" epoch of Wegmann, the younger has been termed the "Nagssugtoqides"; its folding axes strike N.E.-S.W.

What is known of the Nagssugtoqides may be divided into three main zones according to degree of regional metamorphism: (1) a southern gneiss zone belonging to amphibolite and epidote-amphibolite facies, (2) a central one belonging to granulite facies, and (3) a northern zone also belonging to amphibolite and epidote-amphibolite facies.

Although pegmatites are common in the central zone, they are not nearly so numerous as in the two zones of lower facies, evidently because fissures and other places of low pressure favouring a local concentration of migrating material do not form so easily under the P-T conditions prevailing in the deepseated granulite facies.

SHORTLY after the war, the Geological Survey of Greenland was established under the charge of: K. Oldendow, Director of the Greenland Department, H. Ødum, Director of the Geological Survey of Denmark, A. Rosenkrantz, Professor at the Technical High School, and Arne Noe-Nygaard, Professor at the University of Copenhagen.

The field work has now been going on for three summers, and besides smaller and more casual investigations, three main lines in the geology of Greenland have been followed up: the Tertiary basalts, the Cretaceous-Tertiary sediments of the central West coast and the Pre-Cambrian basement complex of which a reconnaissance map covering the area between 66° and 69° has now been made. Being responsible for this particular part of the work I offer this paper on some of the results which I consider of more than local interest. My second in command, Dr. Hans Ramberg, has been the first man in the field during the whole work, and his is also the greater part of the results mentioned in this paper; a varying number of younger geologists have taken part in the field work as well as in the later work in the laboratory.

Between 66° and 69°, remnants of two old chains of folded mountains have been recognized. They meet and are welded together in the region of the outer part of Søndre Strømfjord-Itivdlinguak, where a marked zone consisting of rocks of a considerably lower degree of metamorphism (soapstones, talc, etc.) than the surrounding gneisses, has been encountered. The southern orogeny is the older one, and so far only the northernmost part of it has been more closely investigated; preliminarily it has been designated the "Kangamiut complex." This complex is rather homogeneous and remnants of obvious sedimentary origin are not common; it has been formed or has at least undergone re-crystallization and metasomatic alteration under regional metamorphic conditions corresponding to the granulite facies.

Suggestive of a period of widening after cessation of the orogenic movements is a thick swarm of vertical or almost vertical diabase dykes, the "Kangamiut diabases." Similar post-metamorphic diabases seem to be common the whole way along the coast of southern West Greenland, but only scattered observations have yet been made. It seems likely that the Kangamiut complex was formed during the Ketilidian orogeny of South Greenland, established and described by Wegmann (Wegmann, 1938).

The younger of the two chains has been traced northwards to the Disko Bay without interruptions, and it has been studied far more thoroughly than the southern one. Ramberg suggests that this orogeny should be named the Nagssugtoqides, because the structures are exceedingly well developed in the region of the Nordre Strømfjord (Greenl. Nagssugtoq), which lies almost in the middle of the area so far investigated.

Before describing the Nagssugtoqides as such I must mention the rôle of the Kangamiut diabases, which though definitely older than the regional deformation of the Nagssugtoqides set their peculiar stamp on the whole southern part of the younger chain. Going from the outer coast through the Søndre Strømfjord, one perceives how the almost vertical cross-cutting diabases from the Kangamiut post-metamorphic swarm gradually enters into the plastic deformation of the surrounding gneisses during the younger orogeny. On moving eastwards one sees that the diabases are more and more folded and in the inner part of the fjord broken into large boudins. Another thing is very convincingly demonstrated, namely that the reactivated gneisses to a considerable degree had their main structure dominated by the rigid rocks of the Kangamiut dyke swarm. That means that the gneisses formed during the Nagssugtoqidean orogeny received a foliation which on the whole coincides with the original strike of the dykes in the regions lying not too far off from the old Kangamiut complex. To north and east the structural-controlling effect of the diabases diminishes and the alteration of the diabases increases. Since the diabases can be followed into the younger chain for long distances, there can be little doubt that a considerable part of the enclosing gneisses are also reactivated rocks of the older Kangamiut complex, although special characteristics have not yet been demonstrated with certainty.

The Nagssugtoqides were folded along N.E.-S.W. striking axes, which between Søndre Strømfjord and Nordre Isortoq have a south-westerly dip. In Nordre Isortoq the axis plunges eastwards, and still farther north it is almost horizontal. The natural division based on the intensity of the regional metamorphism of the old chain is the following: the southern third belongs to amphibolite and epidote-amphibolite facies, a central zone belongs to granulite facies, and the northern third again belongs to amphibolite and epidote-amphibolite facies. The three zones are named the Ikertoq, the Isortoq, and the Egedesminde gneiss complexes respectively, and their boundaries can be traced on the accompanying map (Fig. 1).

Between the Ikertoq and the Egedesminde complexes, great similarities exist; both consist of a granodioritic gneiss as the main rock, the gneiss carrying biotite and often common green hornblende and/or epidote. In the gneiss amphibolitic bands and boudins are found; ultrabasic rocks are only seldom included in the complex. Differences between the two complexes are the following: in the Ikertoq gneiss rusty-coloured zones containing pyrites and graphite are often met with; in the same complex a few occurrences of remnants of marble are also found. In the Egedesminde complex so far no marble has been encountered, but the gneiss here contains broad zones of albite porphyroblastic schists, unknown in the Ikertoq complex. On some small islands near Egedesminde a staurolite-garnet-schist has been found; similar rocks were not seen in the Ikertoq complex, nor were some volcanic greenstones occurring on the island Ujaragtafik, north-east of Egedesminde. Another difference, already touched upon, also exists. Compared to the Egedesminde gneiss, the Ikertoq gneiss is richer in amphibolitic bands with partly preserved discordant structure (i.e., remnants of the pre-Nagssugtoqidian Kangamiut diabases).

Numerous pegmatites occur in both complexes. Potash feldspar, acid plagioclase and quartz are the main minerals, biotite, garnet, and hornblende are not infrequent, diopsidic pyroxene is found now and then; it is remarkable that muscovite is very rare. The pegmatites are poor in " rare minerals," so far only beryl and allanite are recorded in some pegmatites.

The Isortoq complex constitutes the central part of the Nagssugtoqides. The main rock is a hypersthene-bearing quartz-dioritic gneiss (an enderbite; similar to the main gneiss of the Kangamiut complex of the older folding chain).

The enderbitic gneiss may be homogeneous over rather wide areas, but generally it is full of schlieren, inclusions and boudins of hypersthene-bearing amphibolites. In the enderbites MnO-poor garnet, brownish titaniferous hornblende, and diallage may be present in various quantities; it is, however, only in rare cases that potash feldspar develops as independent grains, giving rise to a gneiss type of mangeritic or charnockitic composition.

Besides the definitely higher degree of metamorphism of the Isortoq complex as compared to the complexes north and south of it, there is also a general difference in composition. The enderbitic gneiss complex is poor in potash, poor in water, and the Fe···/Fe·· is small compared with the main gneiss of the Ikertoq and Egedesminde complexes.

In the Isortoq complex of gneisses developed in granulite facies, sillimanite and garnet-rich graphite-carrying types of gneiss are common, for example at Utoqat in Amerdloq and in the fjords

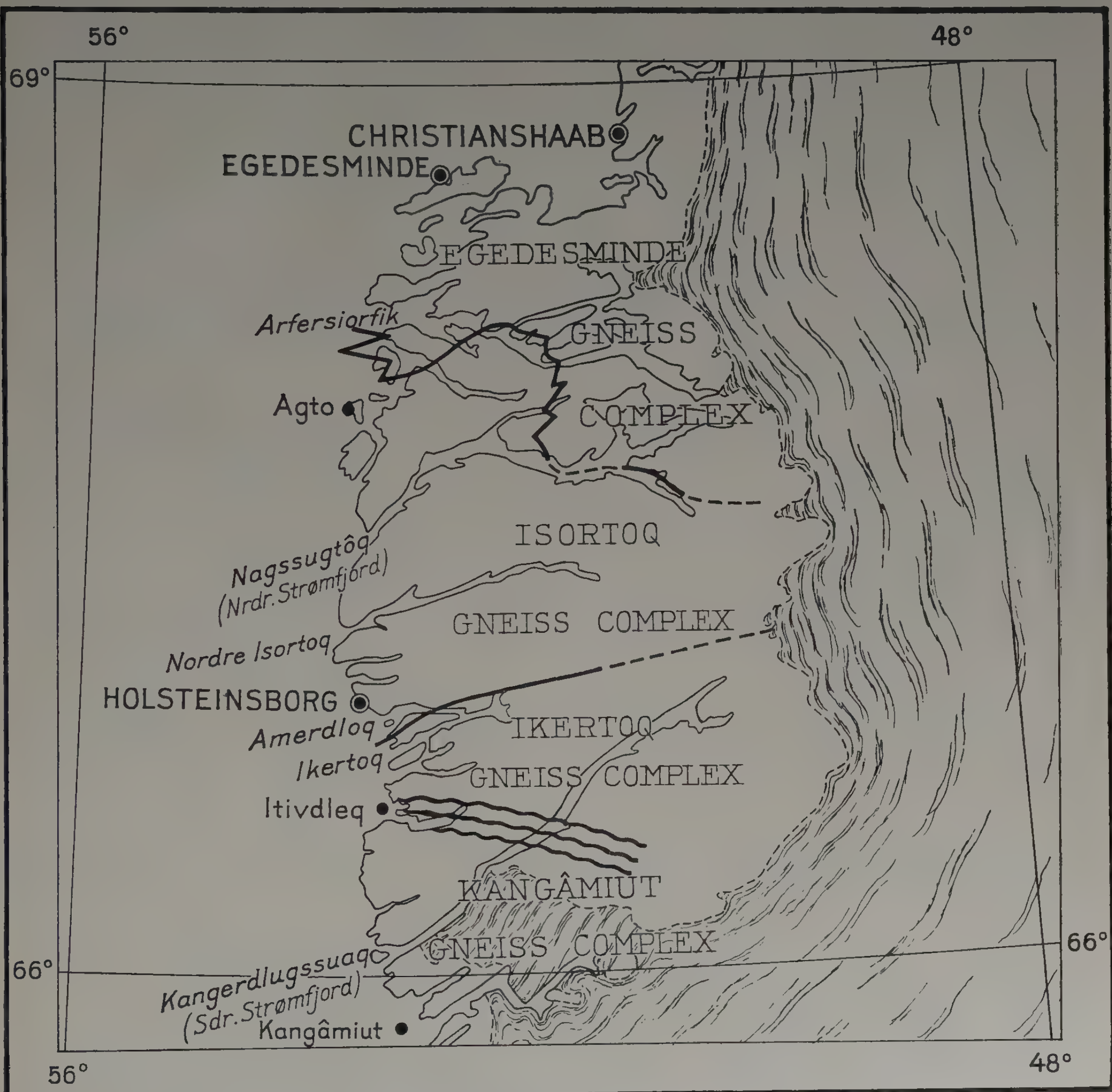

FIG. 1.—*Geological outline map of a part of West Greenland.*

of Isortoq and Nagssugtoq; in the last named place cordierite joins sillimanite and garnet thus forming kinzigite. It is an interesting fact that potash feldspar is much more abundant in these Al-rich rocks than in the enderbitic gneisses themselves.

Rusty zones rich in pyrite and graphite and often containing garnet and biotite are common among the kinzigites and khondalites, but they also occur in the pure enderbitic gneisses. Their significance for the detail work and the tracing of the single synclines and anticlines over large areas is evident. The ore minerals of the rusty zones have been examined by Hans Pauly.

In the fjords of Amerdloq, Isortoq, and especially Nagssugtoq, a number of extensive layers of coarse-grained marbles are present, some of which were already mapped roughly by Kornerup (1879). These marbles, which are generally more or less metasomatically altered into diopside-scapolite skarn, have developed quite a number of " reaction minerals." The occurrences in Amerdloq have been examined by Hans Pauly, too, who records the following minerals from these inclusions in the enderbites: calcite, diopside, scapolite, quartz, sphene, orthoclase, apatite, wollastonite, mica, red and yellow garnet, microcline, hornblende and a violet mineral not yet analyzed chemically, magnetite, hematite, ilmenite, pyrite, chalcopyrite, pyrrhotite.

In some places the newly formed rigid lime silicate skarn has been broken into pieces which are successively distributed in the more plastic surrounding quartz-feldspathic gneisses in a manner comparable to the behaviour of the also rigid amphibolitic pieces of diabasic origin.

Pegmatites are numerous in the Isortoq gneiss complex, though they are not so frequent nor so typically developed as in the Ikertoq and the Egedesminde complexes. This should most likely be interpreted as a pressure effect, i.e., fissures and other places of low pressure, which might be able to favour the formation of pegmatites, will not form so easily under conditions prevailing in the deep-seated granulite facies complex as in the more high-lying amphibolite and epidote-amphibolite facies of the Ikertoq and Egedesminde complexes.

A very striking feature is the influence of the environment—the host rock—of the pegmatites on the formation of certain of the pegmatite minerals. The mineral content in general is the following: potash-feldspar, plagioclase and quartz as major constituents, garnet, hypersthene, biotite, and ilmenite as minor constituents. In the graphite-bearing khondalites the pegmatites develop flakes of graphite; when occurring in skarn of marble, diopsidic pyroxene, sphene, scapolite and hornblende become typical constituents of the pegmatites. Garnet and cordierite are crucial minerals of the pegmatites encountered in the cordierite-garnet gneisses in Nagssugtoq. In environs in the gneisses with a gabbroic bulk composition biotite and plagioclase will increase at the expense of potash feldspar.

After this brief summary of the results of the investigations in West Greenland, an interpretation of the formation of the gneisses encountered in the described complexes will be attempted.

First and foremost it can be stated that the Nagssugtoqides were formed by orogenic deformation of a geosyncline extending in an east-westerly direction north of the Kangamiut complex. The full connexion between the geosyncline of the Nagssugtoqides and the Kangamiut diabases has not yet been established, but it is not unlikely that the diabases represent the feeding channels for the geosynclinal basalts; the reason for this assumption is that parts of the intensively metamorphosed basic layers in the Nagssugtoqidian gneisses in all probability must be considered remnants of such basalts although in the present intensively transformed area no remnants of clear volcanic structures have been ascertained.

There can be little doubt that the greater part of the altered limestones, the aluminous sediments (kinzigites, khondalites) and muddy rocks (rusty pyrite-and graphite-bearing zones) are remnants of the sediments of the Nagssugtoqidian geosyncline. On the other hand, it is not unlikely that some of the most altered and agmatitized inclusions of e.g. skarn rocks in the gneisses are sedimentary remnants of an earlier period of orogeny. The older Kangamiut complex also contains remnants of marbles and zones with pyrites and graphite, and since the field studies show that the southernmost part of the Nagssugtoqides—the Ikertoq gneisses—is a reactivated Kangamiut gneiss filled with diabases,

it is reasonable to believe that some of the old sedimentary inclusions of this complex have survived the younger orogeny, too.

It is remarkable that metamorphic rocks of obvious sedimentary origin are only sparsely developed among the Nagssugtoqidian gneisses, and that the rusty graphite-bearing zones, the sillimanite-garnet-bearing khondalites, are developed in the form of rather thin but very intensely folded layers; further that throughout the gneisses which have been investigated, quartzites are almost completely absent. The natural question to put, would be, where, then, are the thick geosynclinal sediments found? The answer seems to be that the greater part of these are now hidden under the form of some of the different quartzo-feldspathic gneisses.

As mentioned above, the Isortoq gneiss complex was formed at a somewhat lower level in the crust than the two marginal complexes. Since a large scale diffusion evidently was an important factor in the whole story of the Nagssugtoqidian orogeny at the levels in question, and since the position of the Isortoq complex was below the Ikertoq and Egedesminde complexes, one might expect a more or less vertically directed diffusion of elements between the complexes.

Considering the rocks we find that H_2O was squeezed out of the mineral lattices in the gneisses of the Isortoq complex with the deepest position, therefore hypersthene, garnet, and sillimanite developed at the expense of hornblende and micas, and the water was forced to diffuse to higher levels, where epidote, hornblende, biotite, muscovite, and other hydrous minerals come into existence—in the Ikertoq and Egedesminde complexes. Of course not only the gravitative diffusion but also the temperature would work in the same direction.

Similarly the large atoms of potassium were squeezed out of the Isortoq gneisses, leaving enderbitic rocks here and giving rise at higher levels to the granitic and granodiotitic gneisses of the Ikertoq and Egedesminde complexes. Only in two ways could potassium be preserved in the granulite facies rocks, viz. in fissures and places of low mechanical pressure where potash-rich pegmatites were formed, and in rocks with a high concentration of aluminium (kinzigites and khondalites).

The average degree of oxidation is higher, too, in the Ikertoq and Egedesminde rocks than in the Isortoq gneisses. This seems to be due to a squeezing out of oxygen at deeper levels and its tendency to an upward directed migration.

The material affected by the processes briefly discussed in this paper were in part the sediments and volcanic rocks of the Nagssugtoqidian geosyncline, in part the old pre-Nagssugtoqidian crystalline basement. Apparently, the story of the Nagssugtoqidian folding is best understood if we consider the different processes as working towards a re-stabilizing of an unstable part of the earth's crust, and if we consider the compression of the geosyncline and the metamorphic recrystallization of the material with its segregation-pegmatites and its large-scale migration of activated atoms, ions or molecules through the rocks which were in a solid or sub-solid state as intimately connected.

The present paper has been worked out on the basis of a report from Dr. Ramberg (Ramberg, 1948) supplemented by observations by the author and a number of younger Danish geologists.

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DISCUSSION

E. Wegmann: Nous exprimons notre gratitude et notre admiration pour cette communication magistrale. M. Noe-Nygaard a été trop modeste pour souligner la portée fondamentale de sa decouverte. La Greenland est le pont entre la Fennoscandie et le bouclier Canadien. Pour la coordination du Précambrien les cycles du Groenland sont de la plus grande importance. Nous connaissons actuellement les cycles suivants: le Prékétilidien, le Kétilidien, le Nagssugtoquidien, et probablement encore un cycle précambrien plus au nord. Il y a donc autant de cycles qu'en Fennoscandie. On connait en outre le cycle calédonien avec ses phases tardives, dévoniennes et carbonifères, et enfin le cycle commençant à peu près avec le Mésozoique.

CAULDRON SUBSIDENCES OF THE OSLO REGION

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ABSTRACT

The four most evident cauldrons are described, the Bærum cauldron, the Glitrevann cauldron, the Sande cauldron, and the Drammen cauldron. The three first-mentioned cauldrons are large (diameters between 12 and 15 km.); the last one is smaller (diameter about 7 km.). The subsidence amounts to about 2000 m. (possibly up to 3000 m.) for the Bærum and the Glitrevann cauldrons, and between 500 and 1500 m. for the Sande and the Drammen cauldrons.

The three large cauldrons demonstrate various intensities of intrusive activity into the subsided block of lavas during and after the subsidence: The Bærum cauldron has one complete ring dyke around the lava fields (and pre-subsidence intrusions), while the Sande cauldron contains only remnants of the plateau lavas between the ring intrusions and a central plutonic body. The Glitrevann cauldron represents an intermediate stage of evolution.

All cauldrons have been cut by later batholiths. The three larger cauldrons have lost minor sectors, while the whole of the smaller Drammen cauldron swims in a later granite batholith.

INTRODUCTION

THE existence of cauldron subsidences in the Oslo region has been known for a long time, but very little has been published about them. It is therefore the purpose of this paper to give a brief survey of the geological features of the four most prominent cauldrons of the region.

The true nature of the Bærum cauldron was recognized by Schetelig (1918, p. 880), and parts of it have been described in detail (Holtedahl, 1943, pp. 29-43; Sæther, 1945; Oftedahl, 1946, pp. 17-36). The Glitrevann cauldron is mentioned as a volcanic sink by Brögger (1933, p. 123), and was briefly described by Holtedahl (1943, pp. 52-56). The Sande cauldron has never been described; it is mentioned by Brögger (1933, p. 120) as the " Sandelakkolith." Very early Brögger (1895, pp. 126-142) described the Drammen area, emphasizing the tectonic features, and Schetelig (1918, p. 5) mentioned the area as a possible cauldron.

The geological history of the region is as follows: On Pre-Cambrian gneisses, sediments of Cambro-Silurian age were deposited. The thickness of these strata was about 2000 m. During the Caledonian orogeny the sediments were folded, and in early Permian they were denuded to a peneplain. On this peneplain thin layers of sediments were formed, and then the effusive phase of the igneous activity began. A lava plateau was formed, the thickness of lavas being estimated at between 2000 and 3000 m., perhaps more. The effusives consist of a basalt flow at the bottom, then a number of rhomb-porphyry flows, with two basalt flows intercalated in the upper part of the series of rhomb-porphyries. The succeeding plutonic phase began with the consolidation of the larvikite batholiths, the magma of which corresponds to that of the rhomb-porphyries. During the later periods, with the formation of syenitic and granitic batholiths, the cauldron subsidences occurred, accompanied by intrusive activity.

In the following the cauldrons are briefly described, and then a few remarks on their origin are given.

THE BÆRUM CAULDRON

The remarkable features of the Bærum cauldron are the following: early intrusions into the lava flows; then the subsidence accompanied by the formation of a ring dyke; and lastly the proximity to the Krokskogen lava plateau.

The Krokskogen lava plateau shows the following sequence of lavas:—

(top)	Basalt	E_3
	Rhomb-porphyries	RP_{10}-RP_{12}
	Basalt	E_2
	Rhomb-porphyries	RP_1-RP_9
	Basalt	E_1
(base)	Permian sediments	

The designations E_1, RP_1, etc., are those used in the papers of W. C. Brögger and on the geological quadrangle maps, scale 1:100,000, edited by Brögger and Schetelig. The thickness of the exposed series amounts to nearly 1000 m., but the original thickness forming the plateau may be estimated as at least 2000 m.

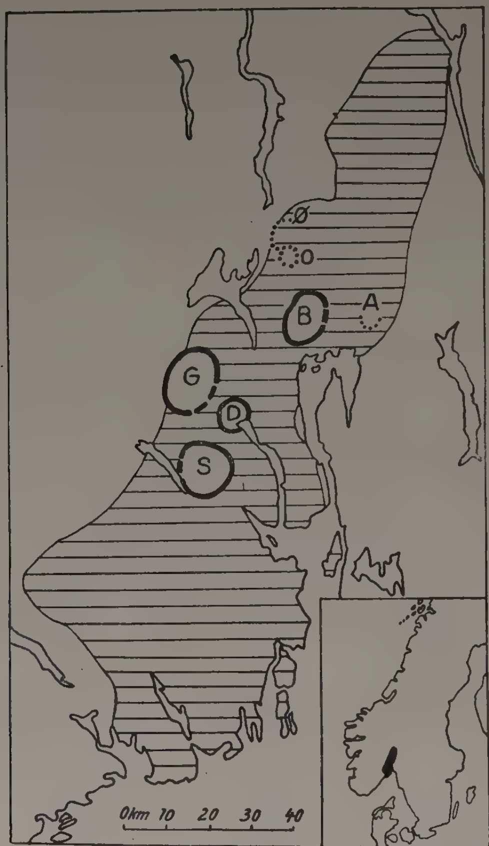

FIG. 1.—*The Oslo region in relation to the surrounding areas of Pre-Cambrian gneisses* (*white*).

The cauldron boundaries are shown by thick lines. B: The Bærum cauldron. G: The Glitrevann cauldron. S: The Sande cauldron. D: The Drammen cauldron. A, O, and Ø show the location of lava fields, which may represent cauldron remnants. Inset: The Oslo region (black) in relation to Scandinivia.

The rhomb-porphyries within the plateau are distinguished by the shape and size of the phenocrysts. Thus the lavas within the Bærum cauldron have been determined to be flows belonging to the top of the series, indicating that the subsidence amounts to at least 1000 m., probably 2000 m., or even more.

The southern part of the cauldron consists of the lavas RP_{11} and E_3, while the northern part consists of the lavas RP_{12b}, RP_{13} and higher flows $RP_{x,y,z,u}$ of unknown position. These lava fields are now

separated by a pre-subsidence intrusion, which has no doubt approximately followed the border between E_3 and RP_{13} (with RP_{12b}).

The intrusion consists of fine-grained porphyritic rocks, ranging in composition from monzonitic (akerite porphyries in the south-western portion) to syenitic (chiefly in the south-eastern and northern portion). These rocks are intimately associated with breccias, consisting of fragments and detritus of lavas. During a later phase of the intrusive activity felsite-porphyries were intruded, forming sheets and irregular masses. These porphyries carry inclusions, and may in places fade into typical breccias. Chemically the porphyries are potash-syenitic, with an extraordinarily high potash content (up to 7 per cent K_2O).

The pre-subsidence age of the intrusive rocks is indicated by the ring dyke cutting the intrusion, and by the fact that north-west of the cauldron there is an area with just the same rocks associated: akerites, akeritic to syenitic porphyries, breccias and felsite-porphyries.

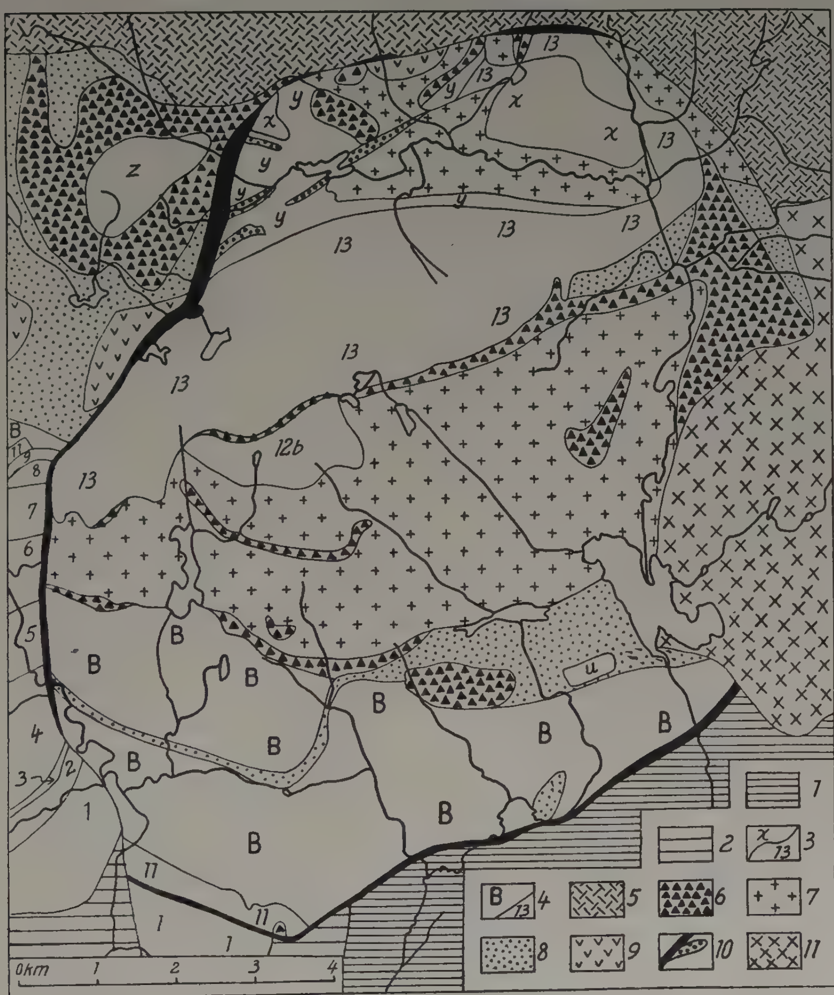

FIG. 2.—*The Bærum cauldron.*

1: Upper Silurian sediments. 2: Downtonian sandstone. 3: Rhomb-porphyry lavas. 4: Basalt. 5: Larvikite and similar rocks. 6: Breccia. 7: Akerite porphyry. 8: Felsite porphyry, in places transitional into breccia. 9: Akerite. 10: The ring dyke (black), with outliers in the cauldron. 11: Nordmarkite.

The intrusive activity took place between the plutonic periods represented by kjelsåsite-larvikite and nordmarkite-ekerite. The subsidence then occurred, possibly in connection with the start of nordmarkite activity. Later the nordmarkite batholith cut a section of the cauldron.

The ring dyke was intruded at a late stage of the subsidence, because in some places it is intensely brecciated, in other places it only seems to be chemically altered. The only intrusions possibly later are some quartz porphyry dykes, not marked on the map of Fig. 2. Even these may, however, be approximately simultaneous with the ring dyke.

THE GLITREVANN CAULDRON

The Glitrevann cauldron consists of remnants of a subsided lava block, into which the following rocks were intruded after the subsidence:—nordmarkite, nordmarkite-porphyry, felsitic breccia, aplitic granite and quartz porphyry. Folded Cambro-Silurian sediments surround the cauldron, and a coarse granite cuts a south-eastern sector of it.

The flows of the lava fields may to a large extent be compared with those of the Krokskogen plateau. The following flows are recognized: E_1, RP_1, RP_2, RP_4 (with smaller zones of RP_5 or RP_6), E_2, RP_{11} and E_3. P_3 is a basic andesite, intermediate between basalt and porphyry. " RP " of Fig. 3 is a higher flow of unknown position. x and y mark well-defined, but uncorrelated, types. Mixture of various types is marked by a question mark.

The map, Fig. 3, shows that the subsidence of the lavas may have occurred in two ways. Either the rocks underwent a " vertical sinking," a parallel movement downwards, or we have a " rotational sinking," where the inner part of a lava field subsided, while the outer part, bordering the ring-fault, only sank a little. By this type of sinking the lava field was exposed to a rotation, eventually combined with subsidence. The south-western lava field (see Fig. 3) is the most beautiful example of rotational sinking. The rotation is more pronounced in the north-eastern lava field, and the little lava zone is rotated through nearly 90° at the southern border, where a number of different rocks form small vertical lenses.

The intrusions of the cauldron may be classified as follows:

(1) The south-western peripheral ring dyke.
(2) The complex central syenite intrusion with breccias and an interior northern ring dyke.
(3) The south-western interior ring dyke.
(4) The central intrusion.

Between Skogsvann and Lauvtjern intrusions of nordmarkite-porphyry approximately follow the western border of the cauldron. They are clearly younger than the subsidence. At the southern border there are two zones of porphyry, one of which exactly follows the border, wedging out towards Svarttjern into a spherulitic felsite.

The complex syenitic intrusion consists of a coarse-grained nordmarkite north of Stordammen. The rock is a syenite with alkali feldspar and ordinary hornblende. It fades into fine-grained to felsitic porphyries to the west. To the east the intrusion narrows and continues as a ring dyke, consisting of typical nordmarkite-porphyry. The fact that this rock in two places is bordered on its inner side by intensely crushed hornfels, indicates that the rock is younger than the subsidence.

The quartz porphyry ring dyke to the south-west covers a quarter of the cauldron outline. The rock has a marked flow structure in many places. This structure is beautifully developed, because the rock is heterogeneous, with alternating light grey and violet bands. A possible continuation of this ring dyke is found along the north-western and the north-eastern border.

The central intrusion consists of an aplitic granite to the west, fading into a quartz porphyry to the east. This quartz porphyry carries red orthoclase and smoky quartz crystals in a black felsitic groundmass.

Some special rock types are marked on the map. The light syenitic rock north-west of Glitrevann is a fine-grained, non-porphyritic rock of unusual appearance. The breccia north-east of Glitrevann consists of a syenitic felsite carrying inclusions of different lava types; it is similar to many of the

breccias in the Bærum cauldron. The other breccia areas represent either local brecciation or xenoliths of early-formed breccia.

The coarse Drammen granite follows the border for a certain distance to the north-east, but it clearly cuts the cauldron to the south-east, indicating its younger age.

The eucritic gabbro at the northern border of the map belongs to the hybrid rocks, selvedging the plutonic mass to the north.

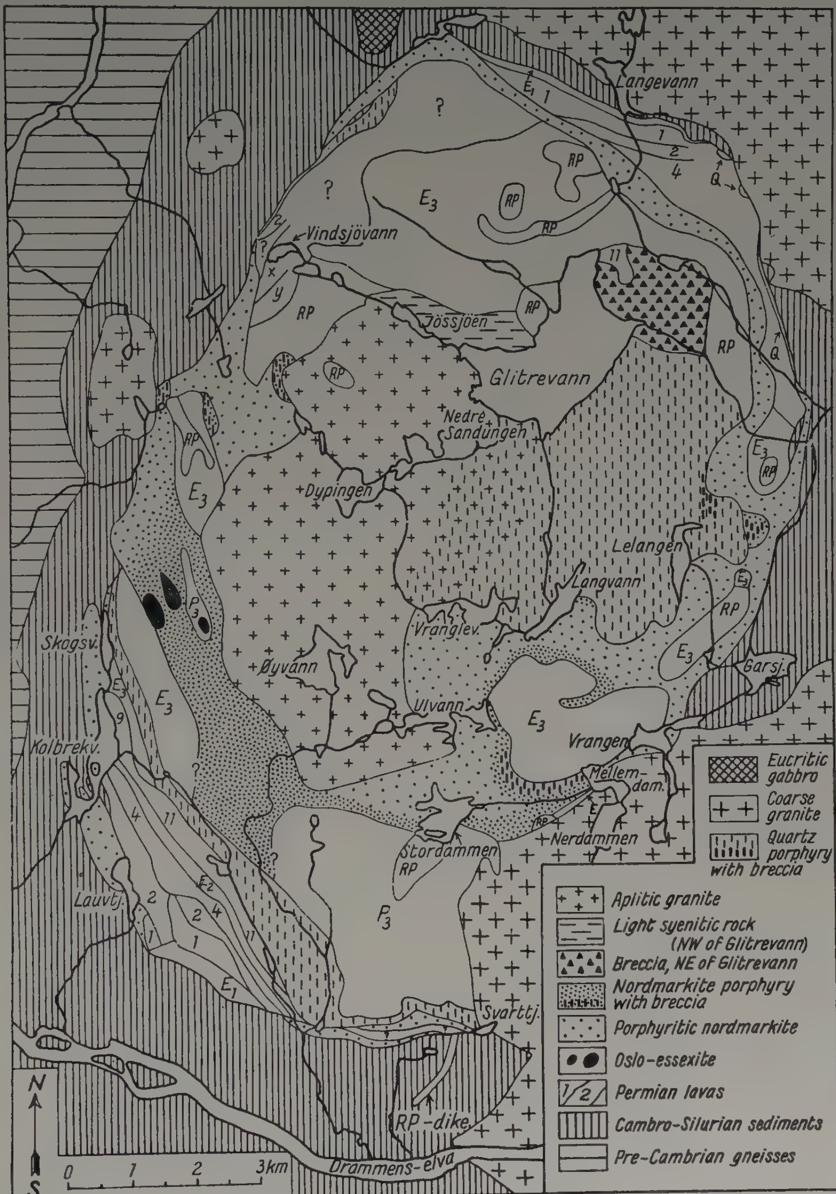

FIG. 3.—*The Glitrevann cauldron.*

The age relations within the cauldron are not completely established. It is certain that the central intrusion is younger than the Glitrevann breccia and the complex syenitic intrusion. From this, and from more indeterminate contacts, it is supposed that all the syenitic rocks are older than the granitic rocks.

THE SANDE CAULDRON

Between the Sande valley and lake Eikern there is a region with densely forested hills, with heights up to 500 m. Most of the region is occupied by a nearly circular, plutonic mass which Brögger called the "Sandelakkolith." This plutonic mass is, however, surrounded by a zone of lavas and fine-grained intrusive rocks. My field investigations show that the lavas have subsided in relation to the surrounding rocks, so that the region is really a cauldron.

The type of subsidence is evidently a vertical sinking along the northern border, while there is a beautiful rotational sinking along the eastern border. Here the Downtonian sandstone is overlain by the lowest basalt, followed by the rhomb-porphyries Nos. 1, 2 and 3 towards the west. The contact between the sandstone and the basalt is exposed 1·3 km. N.N.W. of Sande. The boundary is developed as a tectonic breccia with angular inclusions (size up to several metres) of sandstone in the basalt, and *vice versa*. In the west the cauldron is cut by the later ekerite batholith. The relations along the southern border are not clear.

It has not been possible definitely to establish the stratigraphy of the lava series within the cauldron. The subsidence may be estimated very approximately at about 500 m., probably not exceeding 1000 m.

The ring dyke surrounding the cauldron consists of a quartz porphyry with scattered small quartz and feldspar phenocrysts in a microcrystalline and fine-grained macrocrystalline groundmass. The

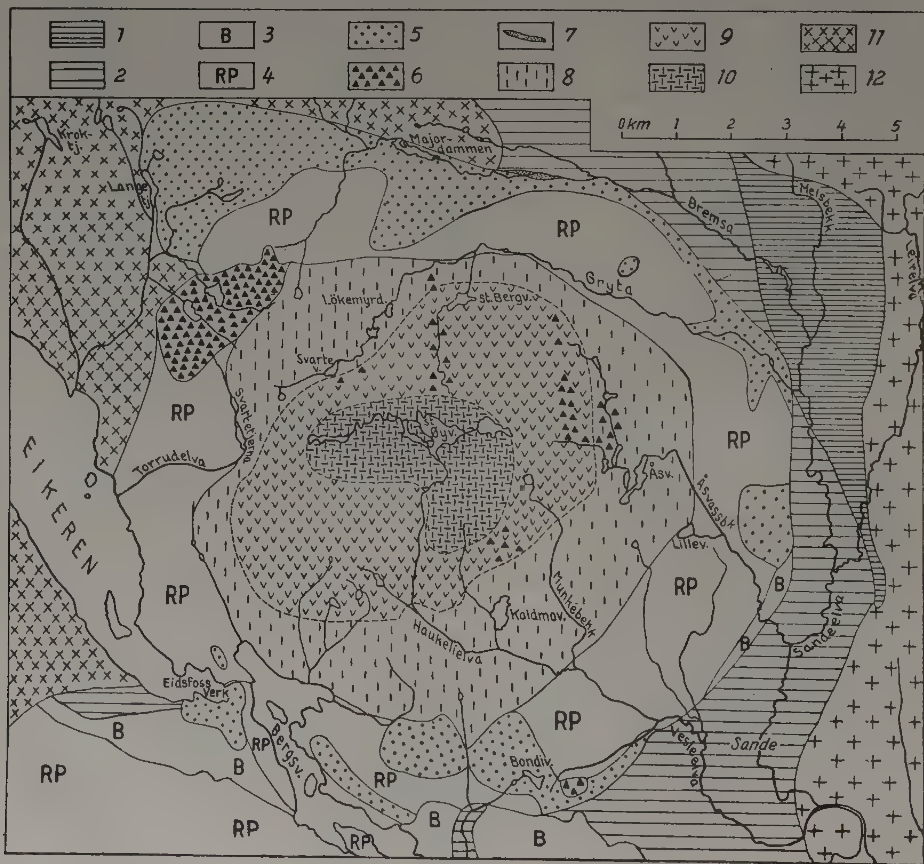

FIG. 4.—*The Sande cauldron.*

1: Upper Silurian sediments. 2: Downtonian sandstone. 3: The lowest basalt. 4: Rhomb-porphyry lavas. 5: Quartz porphyry fault intrusion. 6: Breccia. 7: Rhyolite. 8: Quartz-poor ekerite. 9: Nordmarkite. 10: Monzodiorite. 11: Ekerite. 12: Granite.

irregular southern portion is rather heterogeneous, consisting of transitions to spherulitic and felsitic porphyries and breccias. A younger rhyolite is found at the northern boundary.

The ring dyke is younger than the subsidence, but older than the central intrusion and the western ekerite batholith, according to the following observations: exposures along the river Bremsa show that the sandstone is intensely crushed along the contact with the ring dyke, as are rhomb-porphyry xenoliths lying in the ring dyke south of Majordammen, while no brecciation is seen in the ring dyke. The contact between the ring dyke and the ekerite of the central intrusion is found at Saga, between Eidsfoss and Sande. There is an even transition from ekerite to a quartz porphyry with felsitic groundmass, indicating that the ekerite is the younger rock, which has produced a " diffusion " contact. The western ekerite batholith has a chilled margin towards the ring dyke south of Langetjern.

In the north-western part of the cauldron there is a breccia of approximately the same age as the ring dyke. The breccia consists of a felsite-porphyry carrying inclusions of lavas. It reminds one very much of the Lathus porphyry and the Glitrevann breccia.

The central intrusion is concentrically built, with an outer margin consisting of a quartz-poor ekerite (aegirine-granite), a transitional zone of nordmarkite (syenite to monzonite with alkali amphiboles), and a central portion of basic augite-bearing monzonite to monzodiorite (kjelsåsite). According to the geological quadrangle map " Moss " by Brögger and Schetelig this intrusion should consist of ekerite, nordmarkite, pulaskite, larvikite, and kjelsåsite, with sharp boundaries between all rock types. There exist, however, no sharp boundaries; the rocks fade gradually into each other. Therefore the boundaries of Fig. 4 are only tentative. In all rocks inclusions have been observed. In the ekerite zone a little area to the east is full of large xenoliths of basalts, up to several hundred metres in size. But the inclusions are found especially in the nordmarkite zone. The inclusions are angular; the size is usually below 20 cm. in diameter. They consist mostly of fine-grained basic rocks (non-porphyritic basalt) and shales; rhomb-porphyries are also frequent. The maximum proportion of inclusions is estimated at between 10 and 15 per cent. In the monzodiorite inclusions are rare.

The observations show that a " high-level assimilation " (Daly, 1933, p. 297) is found in these rocks. The field observations also suggest that the central monzodiorite is a hybrid formed by ekerite assimilating basic rocks. Proceeding towards the monzodiorite from the nordmarkite the inclusions seem to diffuse and disappear. It is easy to imagine that the nordmarkite originated from the ekerite, because the nordmarkite is most often macroscopically heterogeneous, with small spots (0·5-2 cm. in diameter), rich in dark minerals (biotite and amphiboles). These minerals are distinctly smaller than the " ordinary " scattered amphiboles, indicating that the spots represent nearly assimilated small inclusions.

The younger ekerite batholith to the west cuts the cauldron. The rock is an alkali granite with aegirine and arfvedsonite. It is full of pegmatitic nests, as seen in road sections along lake Eikern.

East of the cauldron is a biotite granite, the youngest plutonic rock of the Oslo region.

From the above description it is obvious that the cauldron subsidence took place during an early period of the formation of the ekerite batholith. The age scheme will then be as follows:—

(1) Formation of the lava plateau.
(2) Subsidence of a cylindrical block in connection with the rise of ekerite magma. Ring dyke formed during last phase of the subsidence.
(3) Ekerite magma rising through the fractured lavas of the sunken block, forming the central intrusion. Assimilation.
(4) Rising of ekerite magma; formation of the large ekerite batholith.
(5) Formation of the granite batholith.

THE DRAMMEN CAULDRON

The Drammen cauldron consists of lavas, in which intrusions of quartz porphyry are found. The whole cauldron is surrounded by the younger Drammen granite.

The lavas belong to the lower part of the series: the bottom basalt, and the rhomb-porphyries RP_1, RP_2, RP_4 and RP_7.

The quartz porphyry forms a sheet-like intrusion into the lavas. It represents an offshoot from the biotite granite surrounding the cauldron (Brögger, 1895, p. 140).

On the hillsides east of the Lier Valley are found some rocks, which no doubt belong to the cauldron:—breccia, fine-grained syenitic rocks and large xenoliths of rhomb-porphyry. This rock association is typical for a cauldron, and no such rocks are found elsewhere in the granite.

The breccia carries inclusions of basalts and of fine-grained to felsitic syenite-porphyries. These porphyries also occur as inclusions in the granite and as larger separate bodies. Xenoliths of rhomb-porphyry are also observed; their size may be up to 100 m. across.

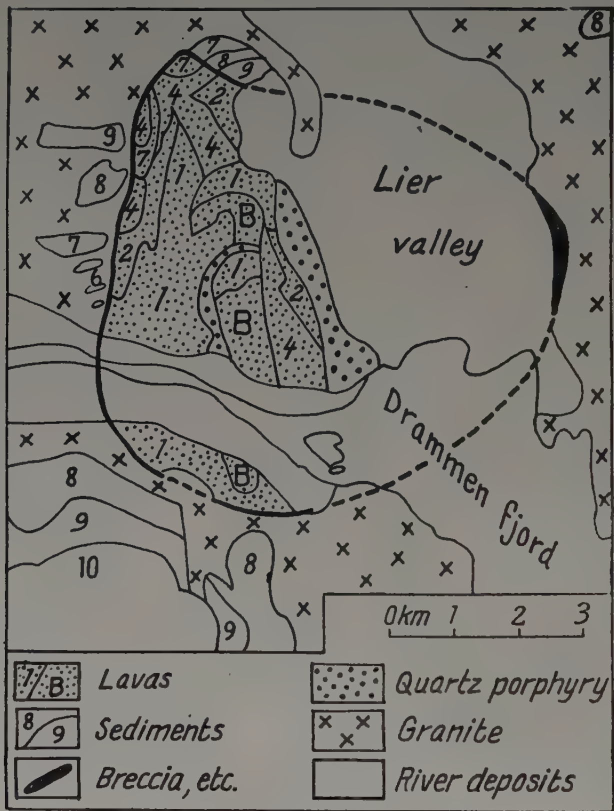

FIG. 5.—*The Drammen cauldron.*

The boundary of the cauldron is marked by a heavy black line. The hypothetical boundary is stippled.

The map, Fig. 5, gives a clear picture of the subsidence. South of the cauldron border, now occupied by the granite, lie upper Silurian strata of stages 8, 9 and 10, according to the Oslo stratigraphical system. Just west of the cauldron small areas of sediments are seen. They could be xenoliths floating in the granite, but I consider them as lying in their original position, because they represent the continuation of the synclines and anticlines of the Bærum-Asker area to the north-east. Thus the subsidence is ascertained, and it amounts to perhaps 1000 m. or more, and not less than 500 m.

POSSIBLE CAULDRONS

The Alnsjø area, just north-east of Oslo, is considered by Holtedahl (1943, p. 25) to represent part of a cauldron, the northern half of which has disappeared into the later nordmarkite.

There are two other areas which possibly contain remnants from cauldrons, now floating in younger plutonic masses. O on Fig. 1 marks the Opkuven area, consisting of a felsitic breccia, with parts of higher rhomb-porphyry flows. Further north there is an area with lavas floating in the younger nordmarkite west of lake Øyangen. A narrow zone of nordmarkite separates these upper lavas from the Silurian bed-rock; thus the lavas have subsided at least 500 m., perhaps 1000 m. or more.

ON THE ORIGIN OF THE CAULDRONS

From the descriptions above it appears that the cauldrons must be classified as some sort of collapse cauldrons. They remind one very much of the Scottish Glen Coe " cauldron-subsidence." But the latter has fault intrusions which are rather large in volume, compared, for instance, with the ring dyke of the Bærum cauldron. Accordingly the Glen Coe subsidence is supposed to represent stoping of a cylindrical block, i.e., by the subsidence the magma was pressed upwards.

The latest classification of cauldrons (calderas) is presented by Williams (1941, p. 246), and in this the Oslo cauldrons would be placed in the group (bV), Glen Coe type of collapse calderas.

But there is another hypothesis which may explain such cauldron subsidences, and the present author prefers this hypothesis for the Oslo cauldrons.

In the Glen Coe type gravitation is the active agency, while the magma plays a passive rôle. But instead the magma may be the active agency, in the way that a rising magma may also sink again for a time. Then a cylindrical block may follow the magma downwards. Various authors have considered such a magma-sinking as being possible. Thus one of the cauldron types in Reck's classification (Williams, 1941, p. 243) is called " *Rückflüsskalderen*," formed by the withdrawal of magmatic support. The Bærum cauldron with its narrow ring dyke must be explained by this hypothesis, which may also apply to the other cauldrons.

The four cauldrons described show a very marked variation in intrusive activity during and after the subsidence. The Bærum, and probably the Drammen cauldrons have only minor intrusions along the boundary fault. The Glitrevann cauldron contains various types of ring dykes and central intrusions and the subsided block of the Sande cauldron has nearly disappeared through the formation of the large central intrusion. If the intrusive force of the magma just after the subsidence increased still more, the intrusions would increase to plutonic bodies, and then the magma could " eat " (e.g. by stoping) large parts of a cauldron, leading to the structures mentioned as possible cauldrons. But these structures could also originate from stoping of semi-circular blocks into a crystallizing magma reservoir.

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LES SÉISMES EN ASIE MINEURE ENTRE 1939 et 1944
LA CICATRICE NORD-ANATOLIENNE

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RÉSUMÉ

Depuis la fin de 1939 jusqu'en 1944 des séismes ont secoué l'Anatolie septentrionale. Le 27/28. 12. 1939: séismes entre Erzincan et la vallée de Kelkit; zone épicentrale 400 km. contre 6-7; 40.000 morts; intensité X degré; sol fissuré par une dislocation de 350 km.; déplacement horizontal 3,7 m. Le 20. 12. 1942: secousse dans la vallée de Kelkit; zone épicentrale 50 km. contre 3-4; 500 morts, 773 blessés; intensité IX degré; fissure sur le sol de 50 km. avec déplacement horizontal 1,70 m. Le 27/28. 10. 1943: séismes entre Tokat et Kastamonu; zone épicentrale 300 km. contre 3; 3733 morts, 5363 blessés; intensité IX degré; fissure sur le sol de 250 km. Le 1. 2. 1944: séisme dans la région de Bolu-Çerkeş; zone épicentrale 180 km. contre 4 km.; 4000 morts; intensité IX degré; fissure sur le sol 180 km.

Les zones épicentrales de ces séismes se sont allongées suivant la direction des chaînes. Les fissures formées peuvent être reliées en une seule ligne de 850 km. de long. Cette dislocation suit une zone marquée par des formes typiques d'effondrement tectonique. Les séismes en question montrent des relations avec la tectonique régionale. Les zones les plus éprouvées occupent l'emplacement de la limite entre deux unités tectoniques: Chaîne pontique, dont les caractères se rapprochent de ceux des Balkans et Carpathes, et chaînes de l'Anatolie centrale. Cette zone faible paraît être assimilable à la ligne de soudure de Gondwana avec l'Eurasie: je l'appelle *Cicatrice Nord-Anatolienne*.

DEPUIS la fin de l'année 1939 jusqu'au début de Février 1944 des tremblements de terre d'une brutalité formidable ont secoué toute l'Anatolie et en particulier sa partie septentrionale.

Les séismes se sont succédés comme suit:

Le 27/28.12.1939 à 1 h. 57: Séisme catastrophal dans la plaine d'Erzincan, dans le Nord de Refahiye et dans la vallée de Kelkit. La violence terrifiante de ces secousses détruisit entièrement de vastes régions d'une superficie d'environ 80.000 km². Les victimes humaines ont été évaluées à 40.000 morts. Le séisme a été caractérisé par une aire épicentrale très allongée dans le sens N.W. (400 km. contre 6-7). L'intensité maxima, en tenant compte de toutes les circonstances locales, a dépassé le degré X de l'échelle internationale. Par les dégats qu'il a provoqués ainsi que par le grand nombre des victimes, blessés et morts, ce tremblement a dépassé de beaucoup les plus forts séismes connus dans le sol Anatolien. Le séisme s'est amorti très rapidement vers l'Est et vers le S.E. Les chaînes du Munzur faisant partie des Taurus, paraissent avoir arrêté partiellement la propagation. Les isoséistes jusqu'au degré VI se sont serrés vers ces chaînes et c'est seulement celui du degré V qui a pu les dépasser. Au contraire le mouvement s'est beaucoup plus largement développé vers l'Ouest dans le sens des plis anatoliens et pontiques.

La zone épicentrale, outre les fissures dans les terrains meubles, a été traversée par une déchirure continue dirigée vers le N.W. Cette grande crevasse a été suivie sur une longeur totale d'environ 360 km.; sur son trajet les roches elles-mêmes ont été fracturées et des massifs de montagne ont littéralement éclaté. Dans différents endroits, des rejets verticaux jusqu'à 1 m. et des décrochements avec rejet horizontal ont été observés. Dans ces derniers mouvements le compartiment Sud s'est déplacé vers l'Ouest relativement au compartiment septentrional (dans la plaine de Suşehri 1,50, à Resadiye 3,70 m.)

Le 20.12.1942 des puisantes secousses désastreuses se sont déclanchées dans la vallée de Kelkit où, d'après l'allure des isoséistes, une zone épicentrale suit cette vallée depuis les environs de Niksar jusqu'à sa jonction avec le Yeşilirmak. Cette zone a été également très étroite (50 km. contre 3–4 km.) et dirigée vers le N.W. La ville d'Erbaa ainsi que les localités se trouvant sur son trajet ont été entièrement anéanties. Il y a eu 500 morts et 773 blessés. L'intensité du séisme a atteint le degré IX de

l'échelle, en tenant compte des conditions locales. L'isoseiste du degré IV passe par Ordu, Resadiye, Tokat, Amasya, Merzifon, Havza et Bafra.

Pendant ces séismes la vallée de Kelkit a été disloquée par une faille de 50 km. de long, légèrement sinueuse, avec une direction générale W.15° N. La faille commence à l'Ouest de Niksar à 12 km. environ au Nord de l'endroit où la faille de 1939 prenait la direction de E.–W. Sur son trajet le flysch crétacé formant le seuil qui sépare la plaine de Niksar de celle de Erbaa s'est foncièrement crevassé. Des rejets verticaux observés atteignirent 0,50 m. et le compartiment Sud s'est légèrement affaissé. Mais le rejet principal de la faille a été horizontal et le compartiment Sud s'est déplacé dans certains endroits de 1,70 m. vers le N.W. relativement au compartiment Nord.

Le 27/28.10.1943 des tremblements de terre d'une violence désastreuse et rappelant celui de la fin de 1939 ont ravagé toute l'Anatolie septentrionale entre Tokat et Kastamonu. Les secousses se sont repétées à des intervalles irréguliers, accumulant ruines sur ruines. Le premier choc a été ressenti sur une aire de 450.000 km². La zone épicentrale commence à l'Est, à la jonction du Kelkit avec le Yeşilirmak, et se poursuit dans les régions de Vezirköprü, Kargi, Tosya, Ilgaz pour aboutir à l'extrémité S.W. du massif du même nom. Cette zone étroite (300 km. contre 3 seulement) a été allongée d'abord du S.E. vers le N.W. jusqu'au méridien de Vezirköprü; au Sud de cette ville elle tourne légèrement vers l'Ouest pour se diriger enfin vers le S.W. Dans toutes les villes et villages situés dans cette zone 75–80% des bâtiments se sont complètement écroulés (25.000 maisons). Les routes et chaussées ainsi que les ponts ont été partiellement démolis; la voie ferrée a été déformée en onde mesurant de 1–2 m. de diamètre. Le nombre des victimes se monte à 3733 morts et 5363 blessés. L'intensité de ces séismes atteignit le degré IX de l'échelle, toujours en tenant compte des facteurs locaux. Le séisme a été marqué à la surface par une crevasse continue de 250 km. de long qui a traversé les terres labourées, les alluvions et les roches en place. La fracture a suivi l'axe de la zone épicentrale et a abouti à Bayramören à l'extrémité S.E. du massif d'Ilgazdağ. Du còté de l'Est, elle s'est rattachée au Nord d'Erbaa à la fissure créée par le tremblement de terre du 20.12.1942. Des déplacements latéraux ont été également observés.

Trois mois plus tard, le 1.2.1944 des séismes formidables sont venus ravager les régions de Bolu-Çerkeş et les secousses se succédèrent les jours suivants. La zone macroséismique s'étendait sur une surface de 400.000 km²., mesurée entre la Mer Noire, Erzincan, Antakya, Izmir et Edirne. L'intensité dans la zone épicentrale a atteint le degré IX de l'échelle. 21.000 habitations se sont écroulées et 4.000 victimes ont été écrasées sous leurs decombres. Le maximum d'intensité s'est manifesté sur trois zones de choc parallèlement allongées, dont la plus importante commence depuis l'Ouest de Bolu et se prolonge vers l'Est en traversant la voie ferrée d'Ankara-Zonguldak, puis suivant la vallée d'Ulusu jusqu'à l'extrémité S.W. du massif d'Ilgaz où cette vallée se dirige vers le Nord. Cette zone a été également mârquée, le long de son axe, par une faille dont la direction moyenne est N.70°E. Celle-ci se poursuit sur une distance de 180 km. depuis l'extrémité Sud oriental du lac d'Abat jusqu'à la localité de Bayramören où vient aboutir la faille du séisme du 20.10.1942. Sur le trajet de cette dislocation, des maisons, des ponts et des chaussées ont été cisaillés. Les rails ont été déformés en forme de "$\underline{\times}$" et des rejets verticaux ont été observés à plusieurs endroits; mais le rejet principal de la faille était horizontal, le compartiment Sud s'étant déplacé de 3,5–4 m. vers l'Ouest.

On voit, d'après ce qui précède, que tous les séismes qui se sont succédés entre 1939 et 1944, ont eu des zones pléistoséistes allongées, généralement, suivant la direction des chaînes. Ils n'ont pour ainsi dire pas un épicentre proprement dit, mais sont caractérisés par une étroite ligne ou même une surface épicentrale, commençant chacune juste à l'endroit où venait aboutir celle des séismes précédents; quelquefois même les limites se confondant. Ainsi la zone en question suit les lignes structurales du pays et dessinant une convexité vers le Nord, elle reste comme ces dernières parallèle à la côte de La Mer Noire. Les cassures qui se sont formées à la surface, peuvent être également reliées à peu près en une seule ligne d'une longueur totale de 850 km. mesurée depuis l'extremité S.E. de la plaine d'Erzincan jusqu'au lac d'Abat à l'Ouest de Bolu. Il est évident que cette fracture est la trace sur le sol, d'une véritable faille dans la roche sousjacente. Elle suit une zone marquée par des formes typiques

ESQUISSE DES UNITÉS TECTONIQUES DE LA TURQUIE ZONES ÉPICENTRALES DES SÉISMES ENTRES 1939–44.

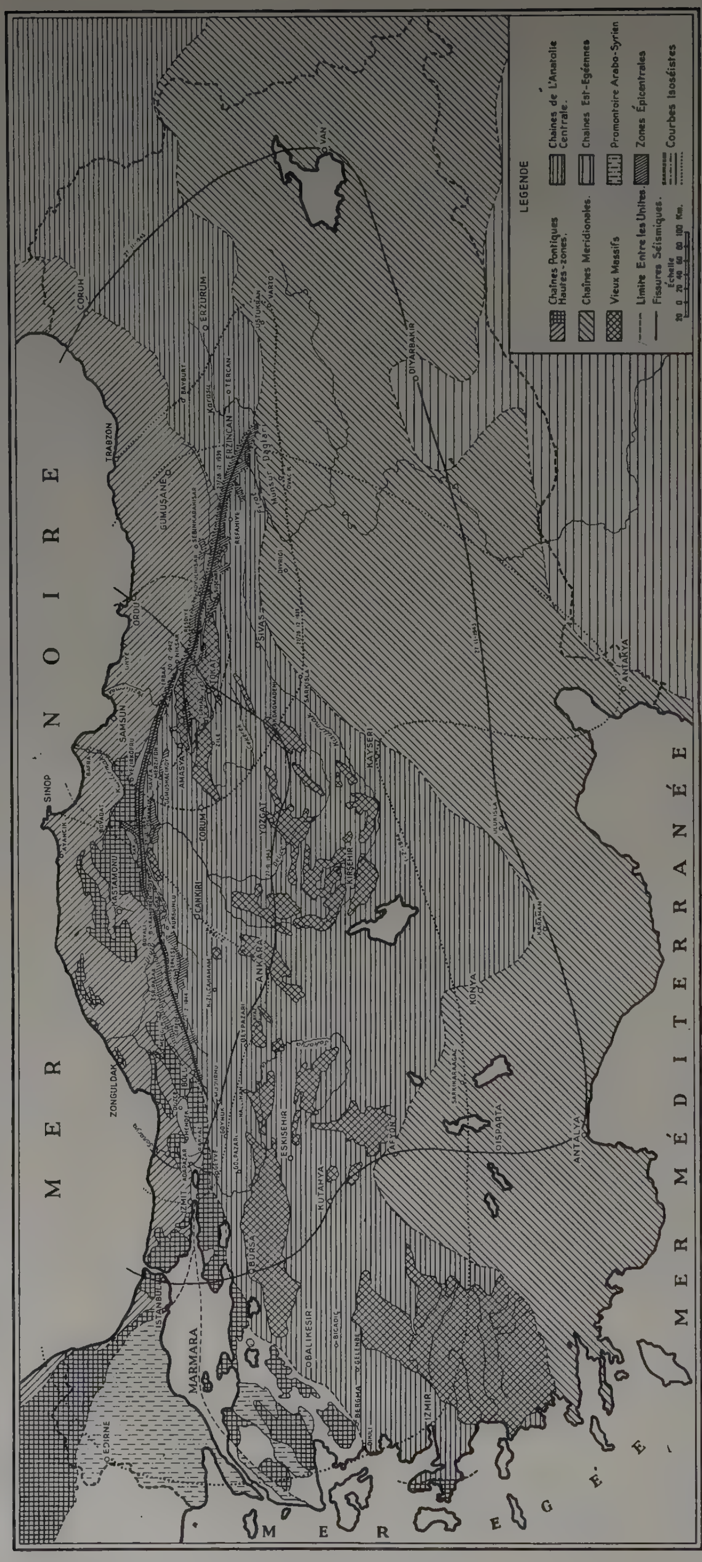

FIG. 1.

de Graben et rift valley qui sont particulièrement bien développées dans les plaines d'Erzincan et de Suşehri, dans les vallées de Kelkit et de Ulusu et dans la zone entre Gerede et Bolu. Ce sont les blocs de cette longue zone faillée qui se sont mis en mouvement de proche en proche par déclanchements simultanés ou successifs.

Le tronçon occidental de cette aire séismique correspond à un corridor de 3–4 km. de large et est couvert de flysch tertiaire d'un faciès tout à fait spécial; c'est un pêle-mêle morcelé renfermant des éléments de différentes roches, le tout laminé et fortement bousculé, comme s'il était pincé et resserré entre deux blocs. D'ailleurs le contact du flysch avec le Nord et le Sud se fait par failles. La limite du flysch éocène avec les calcaires au Globotruncana du Sudest une surface de poussée oblique, le long de laquelle le Crétacé paraît être déplacé sur le Nummulitique.

Le long de la vallée d'Ulusu, la bande du flysch butte au Nord contre une dislocation qui lui procure une délimitation presque rectiligne. Une autre dislocation parallèle à cette dernière, et dans la même vallée, limite le bord méridional de la bande de flysch. Ces deux lignes semblent se prolonger vers l'Est et l'Ouest, et ainsi le flysch broyé occupe une zone effondrée sur une grande échelle.

L'existence d'une dislocation dans la vallée de Kelkit est déjà visible sur la carte géographique par la rectitude frappante du cours d'eau. Le contraste dans le profil stratigraphique, ainsi que dans la structure sur les deux versants, suggère également cette dislocation. Sur le versant Nord une épaisse série de Crétacé, reposant sur le Paléozoique, est couverte par le flysch tertiaire. Des épanchements andésitiques interstratifiés d'abord avec le Sénonien augmentent en épaisseur dans l'Eocène supérieur. Sur le versant Sud, le Crétacé manque totalement; le flysch tertiaire repose directement sur le Paléozoique. Le Nord de la vallée représente un style d'anticlinaux réguliers d'abord largement ouverts et se retrécissant ensuite. Par contre, le Sud est un pays montagneux formé du Paléozoique s'abaissant vers l'Est sous le flysch irrégulièrement plissé. Ici, il n'existe aucune trace d'anticlinaux du Crétacé.

Les séismes en question montrent avec la tectonique des relations indiscutables qui méritent d'être précisées. On sait que dans l'ensemble les chaînes alpines de Turquie représentent les groupements suivants:

(*a*) Une chaîne pontique, englobant deux anticlinaux de fond séparés par un repli synclinal. L'axe de ces anticlinaux subit des surélevations où généralement le Paléozoique affleure. Le caractère des sédiments mésozoiques se rapproche beaucoup de celui des dépôts du segment géosynclinal le plus septentrional des Alpes. Le cycle éruptif débutant au Crétacé supérieur a fourni des andésites et des tufs au cours de la sédimentation du Sénonien. La phase de Vorgosau s'y reconnaît très nettement. Dans la région longeant la Mer Noire depuis le Bosphore jusqu'au delà de Trabzon, les chaînes pontiques montrent une tendance au déversement vers le Nord; mais la structure en écaille cassante avec poussées vers le Nord paraît être générale. Dans le faisceau plus au Sud, l'Eocène et le Mésozoique sont plus plissés, mais toujours avec une fragmentation suivant des cassures longitudinales.

(*b*) Les chaînes méridionales comprenant les guirlandes externes fortement plissées qu'on peut suivre depuis le golfe de Fethiye, au Nord de Rhodes, jusqu'à l'Amanos et qui se continuent vers l'Iran en encadrant le promontoire arabo-syrien. Le tronçon le plus occidental de cette chaîne se raccorde avec la partie centrale par un angle de rebroussement très aigu ouvert vers le Sud, c'est-à-dire dans la direction vers laquelle les plis sont déversés. La chaîne méridionale englobe également une série de plissements internes à structure plus rigide (Taurus proprement dit).

(*c*) Entre ces deux domaines de plissements alpins, il existe dans l'Anatolie centrale une série de chaînes où le sens de déversement des plis est souvent irrégulier. Il s'agit ici des différents faisceaux qui entourent les vieux massifs dont les plus importants sont ceux de Menderes, de Sakarya-Uludağ et de Kizilirmak. Dans ces chaînes intermédiaires, l'orogénèse a souvent affecté les terrains en grande partie consolidés du soubassement. Le Mésozoique moyen et supérieur est représenté par le flysch à intercalation de radiolarites et calcaires massifs lenticulaires. Ces formations sont généralement riches en roches vertes dont l'intrusion a probablement débuté au Crétacé inférieur. L'Eocène à faciès flysch renferme quelque-fois des dépòts lagunaires dans ses niveaux les plus inférieurs. L'Oligocène est souvent lagunaire et gypsifère. Dans le méridien d'Erzincan toute ces chaînes se rapprochent

et se retrécissent fortement; vers l'Ouest de cette région, les mêmes plissements divergent soit pour occuper la grande boucle de Kizilirmak, soit pour contourner du Nord et du Sud les massifs anciens. Vers l'Est de la région d'Erzincan les plis s'écartent de nouveau et s'ennoient en partie dans les plaines de Transcaucasie.

Ce faisceau n'est pas sans analogie avec les virgations du premier genre d'Argand, où les éléments plissés se serrent dans le segment central, et divergent aux deux ailes qui s'ouvrent dans la direction d'extrémités libres.

On remarque que les zones épicentrales des différents séismes occupent la région limitrophe comprise entre les deux unités tectoniques, constituées par les chaînes pontiques et les chaînes de l'Anatolie centrale. Seule, dans la région d'Erzincan, la zone épicentrale des séismes de 1939 est transversale à la direction des plissements. Ici le tronçon de la faille engendrée par le tremblement de terre coupe également la direction des plis. Ceci doit être vraisemblablement attribué à des inégalités dans l'intensité des poussées agissant en chaque point. En effet la convergence de toutes les chaînes anatoliennes dans le méridien d'Erzincan est due probablement au saillant arabosyrien au devant duquel le serrage a été plus intense.

La limite entre les chaînes pontiques et le faisceau le plus septentrional des chaînes d'Anatolie centrale paraît être une importante zone faible. Le segment occidental de cette zone, le fossé de Bolu-Ulusu, dénommé " Paphlagonische Narbe " par E. Nowack, serait d'après lui la continuation de la partie axiale des Alpides sur le sol turc; il coinciderait avec la zone qui sépare le régime alpino-balcanique du régime dinaro-hellénique. Salamon-Calvi voulait assimiler ce tronçon au prolongement de la ligne tonale des Alpes orientales suivant laquelle se ferait la soudure du Continent de Gondwana avec celui de l'Eurasie. En 1941, M. Blumenthal attribuant à cette zone occidentale une importance seulement locale, l'a considérée comme une aire synclinale coincée entre deux haut-fonds d'un plissement; la zone de flysch serait comme un sillon de moindre résistence et de moindre consolidation.

Les observations séismiques et géologiques faites dans les zones les plus éprouvées occupant chacune l'emplacement d'un ancien fossé, paraissent confirmer plutôt l'idée d'existence d'une ligne tectonique d'importance quasi mondiale en Anatolie septentrionale. Les phenomènes de dislocations à l'Ouest se reliant avec ceux de l'Est, formeraient une ligne tectonique ou structurale majeure, comme celle de San Andreas en Californie. Son activité séismique remonte au moins à la fin de l'Oligocène, et depuis des temps historiques les plus reculés elle fût la scène des plus grandes catastrophes. Elle est donc une cicatrice jalonnant la limite des deux unités tectoniques. La formation de cette cicatrice a commencé bien après que le bâti tectonique fût définitivement établi; mais elle continue à être sous tension, puisque les poussées tangentielles, quoique affaiblies n'ont pas cessé leur action.

A ce propos il faudrait rappeller qu'en Anatolie septentrionale les mouvements tectoniques vers la fin du Miocène indiquent, d'une manière générale, une tendance à un plissement dirigé dans le sens des plis alpins; mais le plissement a été gêné par la rigidité des terrains anténéogènes. Dans les anticlinaux de fond où affleurent normalement ces terrains, le Néogène apparaît parfois à la faveur d'abaissements d'axe ou de failles longitudinales, ou bien il occupe des bandes limitées par des failles.

La délimitation exacte des unités tectoniques est généralement chose difficile, malgré l'existence de traits géologiques et tectoniques caractérisant l'une ou l'autre. Mais la zone caractérisée par sa séismicité et par une foule d'autres critères (sources thermales, minérales, failles . . .) paraît établir une séparation parfaite entre les chaînes pontiques et les chaînes d'Anatolie centrale. Cette ligne de disjonction, nous voulons l'appeler: *Cicatrice Nord Anatolienne*.

NEW ASPECTS ON THE LATE-QUATERNARY DISPLACEMENT OF SWEDISH SEA SHORE

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ABSTRACT

The paper summarizes investigations on the marine changes of level in South-west Sweden since the last ice age, carried out by the author in order to define separately the two main factors which have ruled the shore displacement process, viz. the uplift of the land (α) and the variation in height of the ocean level (ω). $\alpha + \omega$ make E, i.e. the actual — positive or negative — movement of the shore. This is analysed by means of a relation diagram for isochronous shore planes. A series of discontinuities have interrupted the emergence of the former sea bottom. Some were ω-effects, others α-effects. The latter were not isostatic, but due to alternating contractions and dilatations causing pulsations of the isostatic elevation dome. The isostatic movement was caused by the flowing back—plastically—of the masses that were forced aside by the load of the ice cap, and is called α^p. The pulsations manifest themselves as effects of elastic deformations of the rising vault (α^e-effects). Co-ordination in time with climate fluctuations, recorded by pollen diagrams, points to thermal impulses for the α^e-factor, and these impulses are suggested to originate from the earth's interior.

SINCE the early twenties of this century it has grown more and more evident that the emergence of large areas of Fennoscandian land, which has taken place after the last Quaternary ice age, is ruled by two opposite main factors, viz. (α) upheaval of the earth's crust, and (ω) rise of the ocean level. Already to the scientists of the eighteenth century it was obvious that the sea had formerly covered the lowlands of Sweden; but for 150 years it remained unsolved whether this fact was due to higher sea level, or lower altitude of the land. In 1890, the question was settled by Gerard De Geer. He showed that the ancient shore planes slope outwards from the centre of the old glaciation area. The geoid had been deformed by the load of the ice-sheet; and after the disappearance of the latter, it has been regaining gradually, in accordance with the laws of isostasy, its normal shape. This explanation of the negative shore movement that dominated the geographical development in Scandinavia during Late-Glacial and Post-Glacial time seemed for thirty years conclusive; and it still remains valid for the bulk of the phenomena. Yet, as Reginald Daly (since 1910), and—with special regard to Fennoscandian conditions—Fridtjof Nansen (1922) and Wilhelm Ramsay (1924) suggested, rise and fall of the sea level caused by changes in balance between ice formation and ice melting on the continents, may also be considered. Thus, for instance, is the " Post-Glacial land subsidence "—described by De Geer in 1882—now explained. Recently, however, the Late-Quaternary epeirogenesis of Scandinavia has proved to be still more complicated. To the isostatic and eustatic factors there is added a third one: a kind of crustal movement, quite independent of the isostatic uplift as to origin and epeirogenic effects. The latter manifest themselves as alternating transgressions and regressions, similar to the eustatic ones, but distinguished from these by their regional variation in amplitude.

In order to get material on the basis of which the isostatic and eustatic factors could be defined separately, the present writer undertook in 1932-1945 a thorough investigation of the raised beaches of the ancient sea fiord that occupied, in Late-Glacial and Post-Glacial time, the valley of the Viskan River in the south-west of Sweden, as well as of the former archipelago of the province of Halland. The field work comprised mainly measuring, morphologically and stratigraphically, cross-sections through the fiord valley and on the slopes of the ancient islands which at present form hills on the coastal plain of Halland, in a number large enough to allow reliable connection of the raised beaches into a system of shore planes. In the laboratory pollen diagrams and diatom diagrams for a large set of series of samples from the fiord sediments, etc., were constructed in order to determine

the stages of development, to control the construction of isochronous shore planes, and to get the whole evolution correlated to the pollen-analytical time system. Through these studies the effects of the isostatic and eustatic factors have been analyzed; but, beside this, the other kind of crustal movement, just mentioned, revealed itself.

The only way to unravel the intricate web of problems which the Late-Quaternary epeirogenesis of Scandinavia has proved to present, is to build up a diagram showing the mathematical relation in height between the ancient shore levels which are now tilted by the land upheaval to different degrees of dip. Such "relation diagrams" were suggested by Ramsay (1926), and practically used for the first times by the present writer (von Post, 1929) and V. Tanner (1930). Furthermore, it proved useful, for the sake of distinctness, to denote the fundamental factors of the epeirogenesis and their effects by symbols (von Post, 1947). Crustal movements in general are called α, and the eustatic factor ω. $\alpha + \omega$ make E, which stands for the epeirogenic shore movement as a whole. Different kinds of crustal phenomena are called α^p, α^e, etc. (see below).

In the relation diagram, the altitude figures for the raised beaches are plotted into a system of co-ordinates, the x indicating the height above sea level of a chosen shore plane—the reference line—at a measuring station, and the elevation of each shore mark of the whole sequence observed at the particular measuring stations. So each series of elevations at a station is placed in the diagram according to the elevation there of the shore plane chosen as reference or datum line (Fig. 1). Consequently, diagram lines combining synchronous shore marks display the mathematical relation

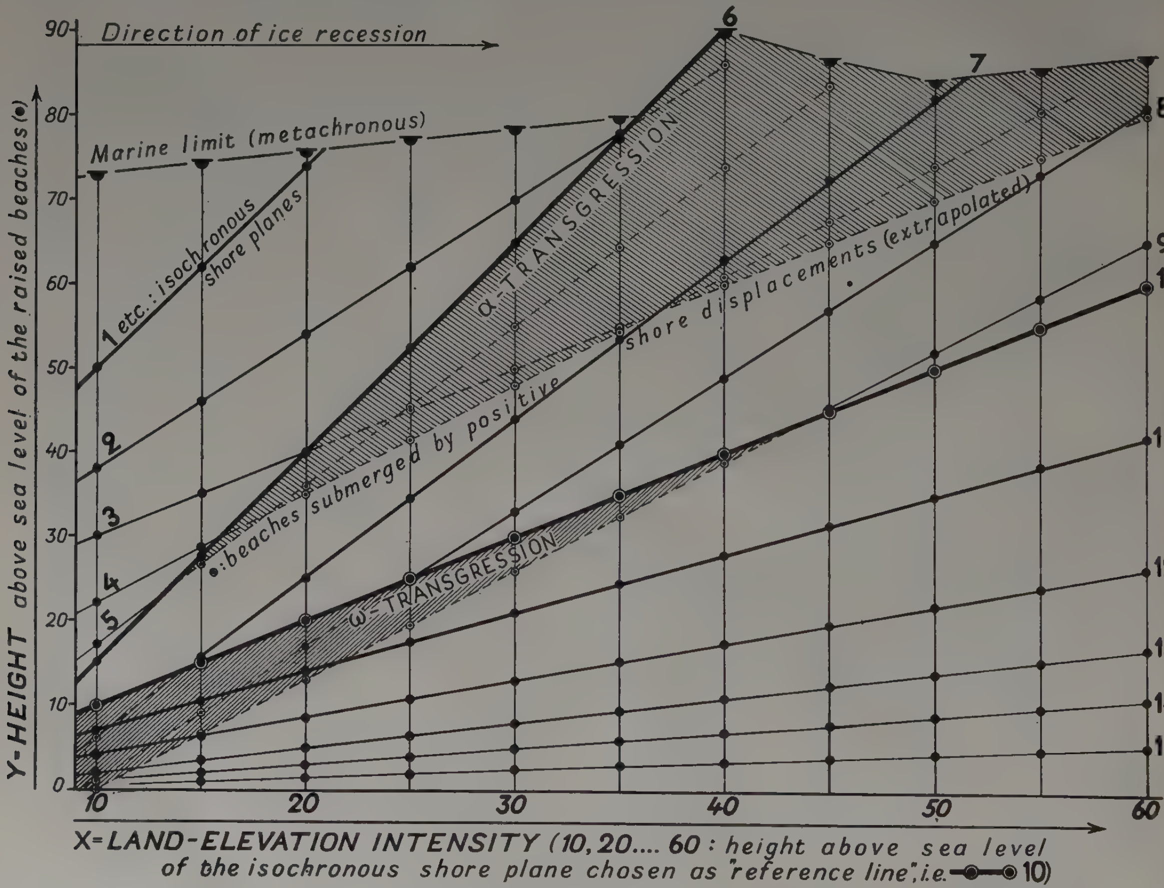

FIG. 1.

Relation diagram for an imaginary sequence of tilted shore planes; schematically after an actual diagram for the marine raised beaches of Halland (von Post, 1947).

between the ancient shore planes of an area, independently of local irregularities of its isobase system, etc. The relation diagram presents the general development within the region from which it is derived. *E*-curves, showing the course of shore displacement at every " isobase latitude " represented, can be taken out from it by means of the *y*-values for its shore-plane lines; and α-curves can be constructed as well, viz. from the gradient angles of the latter (Fig. 2). So, this " method of relative gradients," materialized in the relation diagram, becomes a master-key to the epeirogenic history of an area such as Scandinavia.

For the Halland-Viskan area, and even elsewhere in Sweden, the relation diagram shows a sequence of straight lines representing the ancient shore planes. The straightness of the diagram lines implies that the former horizontal planes are deformed by the land uplift proportionately at all isobase latitudes, their present dip, as a general rule, decreasing from the older to the younger ones. But there are exceptions to this rule. The diagrams also disclose—throughout Gothi-Glacial, Fini-Glacial and Post-Glacial time—a manifold series of transgression waves, now α-effects, now ω-effects, and occurring repeatedly, all while the isostatic land uplift was continuously going on. These transgressions are graphically expressed in the diagrams by the crossing of younger shore-plane lines by older ones. In the case of an α-effect, the younger lines are steeper than the older. The ω-effects are characterized by the crossing shore planes sloping less than the crossed ones. In other words, transgressions caused by crustal movements increase in amplitude with increasing general uplift, i.e. towards the centre of the elevation dome. They interrupted the negative shore movement, the land falling back temporarily, so that the sea shore rose again into positions from which it had previously retired because of the rise

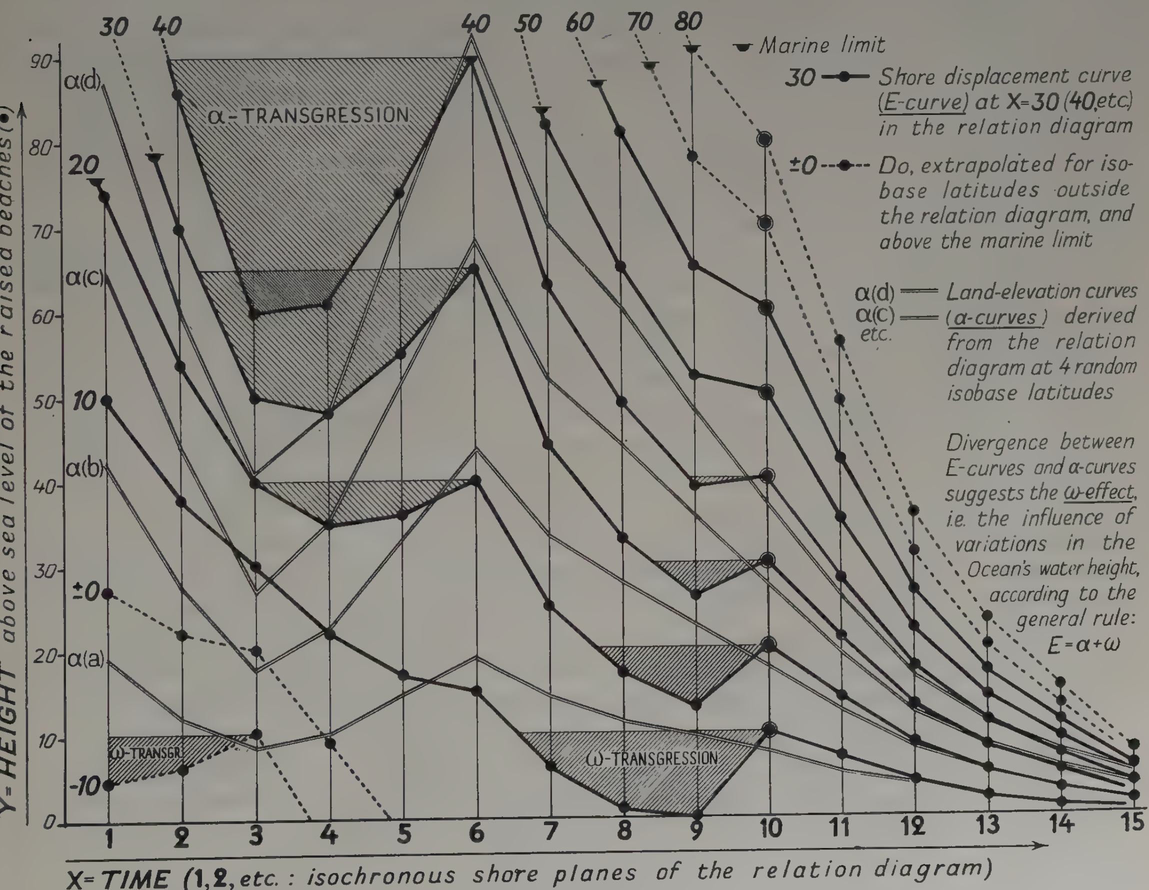

FIG. 2.

E-curves (shore displacement) and α-curves (crustal movement) derived from the relation diagram (fig. 1).

of the crust. On the other hand a transgression that was due to rising sea level had its greatest amplitude at the low isobase latitudes of the marginal region of the uplifted area, and faded gradually away with the increasing land-elevation intensity of its central zones. In this case, the shore plane in question has been lifted uniformly, remaining parallel to its " normal " height position. This distinction between α and ω-transgressions is deducible from the relation diagram itself, but is more conspicuously displayed by the set of *E*-curves derived from it.

Comparison between *E*-curves and α-curves makes the character of a transgression-wave still more unmistakable. If the α-curves exhibit the transgression in the same way as the *E*-curves, it must be an α-effect. In the case of an ω-effect, the α-curves show no parallel to the transgression recorded by the *E*-curves. However, neither the ω-curve—the same at every isobase latitude—nor the α-curve corresponding to a particular *E*-curve, can be determined until the zero-isobase for land elevation has been located. At the zero-isobase the ω-curve matches the *E*-curve. But as long as the situation of the zero-isobase is unknown, only the form of the α-curves, but not the position in the co-ordinate system of the α-curve corresponding to a certain isobase latitude, can be found. In the equation $\alpha + \omega = E$ there are still two variables.

The Halland series of raised beaches begins, approximately, in the 10th millennium B.C., i.e. about the middle of the Gothi-Glacial epoch of ice recession in Scandinavia. From this time on, the relation diagram shows alternating α- and ω-transgressions almost in unbroken succession. Gothi-Glacial and Fini-Glacial α-transgressions culminate, according to the Swedish geochronological time scale (worked out by Gerard De Geer on the basis of the varved clays), at about 8,800, 8,300, and 7,300 B.C., ω-transgressions at about 7,800, 6,800, and 5,500 B.C. This last is the " great Post-Glacial subsidence," described by De Geer. Even this transgression wave is doubtless an ω-effect. It is followed by a Post-Glacial sequence of shore undulations, slightly manifested in Halland because of the low rate of Post-Glacial land uplift in this area, but so much better in, for instance, Södermanland (Sten Florin, 1944). At the higher isobase latitudes of Middle Sweden, all these undulations are in my opinion crustal movements, as suggested already by Florin. The ω-transgressions that occurred also during the later parts of Post-Glacial time, ought to have faded out in Södermanland, and could in any case hardly have had so great an amplitude as the ten metres or so proved by Florin for the shore undulations of this area by his careful examination of the stratigraphy of strand deposits and lagoon sediments. The recognition that the discontinuities in the land uplift of Södermanland are α-effects, and their correlation with the climatic fluctuation, also established by Florin, are important clues to the whole question of the origin of these details of Swedish epeirogenesis.

The Gothi-Glacial and Fini-Glacial ω-transgressions of Halland substantiated a working hypothesis for my investigation of the epeirogenic evolution within the Halland-Viskan district. Without any doubt they are due to fluctuations of the ocean level, caused by climatic changes in the average supply of melt-water to the sea from the continental ice-sheets of the globe. The series of α-transgressions, however, was quite a surprise to me. It represents that third epeirogenic factor, which I mentioned introductorily as an addition to the eustatic and isostatic ones. The α-character of these transgression-waves is made evident by the conformity of the *E*-curves to the α-curves; but just as obviously they are not isostatic. The isostatic land uplift has been going on steadily for tens of millennia at a gradually decreasing rate, though still unfinished at the present time. The motor of the crust's isostatic elevation is the flowing back, in the earth's interior, of the masses that were forced aside through the deformation of the geoid by the load of the land ice. The lag of the isostatic re-elevation process points decidedly to a plastic kind of magmatic movement; and this component of the Scandinavian complex of epeirogenic factors may, therefore, be called α^p. In sharp contrast to the α^p-factor stand the α^e-phenomena, i.e. the short transgression waves, the series of which, as a whole, runs parallel to the α^p-development, its actual curve oscillating, however, up and down about an average corresponding roughly to the α^p-curve. The symbol α^e refers to the cause of this part of the epeirogenic evolution process—elastic deformations of the earth's crust.

The true nature of the α^e-movements reveals itself in the Halland system of raised shore planes.

In particular the transgressions which culminated about 8,300 and 7,300 B.C. present every characteristic of elastic movements. Both are episodes finished within about a millennium. In both cases the transgressions set in suddenly, rise rapidly to their culmination-points, and fall back again almost equally fast. Such transgression waves must result from sinkings of the crust that were—geologically speaking—instantaneous responses to temporary impulses of some kind or another. Evidently, the reaction to the impulse followed exactly the growing and dwindling of the working power; and no effect remained after the direct influence of the impulse had ceased, except a brief lag which is characteristic of elastic deformation. Epeirogenic movements like these could in fact be termed " elastic shocks." So shocking indeed to what has been hitherto held for common sense in Swedish Quaternary Geology, that the whole phenomenon ought to be questioned earnestly unless it can be affirmed by undeniable primary facts established independently of the Halland-Viskan investigation.

The province of Halland represents quite a narrow belt of the Fennoscandian land elevation dome, just within its very border. If transferring the shore plane system of such an area to regions with great intensity of land elevation, one must reckon with so large a margin of error that the calculation might lead entirely astray. Such an extrapolation would be almost worthless if not effectively controlled. Fortunately, however, the control can be afforded. There are a great many curves of Late-Quaternary shore displacement constructed for different parts of Sweden and dated archeologically, pollen-analytically, and even geochronologically. Among these curves, I have compared (von Post, 1947) the three most reliable ones—from Ångermanland (Lidén, 1938), from Gästrikland (Asklund, 1934), and from Södermanland (Florin, 1944) with E-curves for the areas in question, derived from the Halland diagram by extrapolation. The agreement is striking. Especially, the Fini-Glacial " elastic shock " has, beforehand, got a fourfold corroboration. Each of the empirical curves from these areas covers almost exactly the regression phase of its extrapolated counterpart; and even the positive part of this transgression wave is checked by the Late-Glacial transgression of the sea that Maj-Britt Florin (1944) found diatomologically registered in a series of ancient lagoons, extending from some 100 m. to about 155 m. above sea level in the area of Degerfors (" Svea älv "). A fifth corroboration from the central parts of the elevation area was established last summer by the present writer, viz. an " anticline " formed by the marine limit in the area of Brattforsheden (Prov. Värmland), exactly in the region where the receding ice-border passed at the time of the Fini-Glacial transgression shock (von Post, 1948). Such an " anticline " of the marine limit has been sketched in Fig. 1.

Such being the case, it seems inevitable that we accept the shore-plane diagram of Halland as an actual record of the general α^e-effect upon the Scandinavian land elevation dome. Due to the α^e-influence, the rise of the dome, though ruled, on the whole, by the α^p-factor, proceeded undulatorily. In fact, an hypothesis to that effect was produced by Astrid Cleve-Euler (1923) but because of serious mistakes both as to its empirical fundamentals, and in the application, this hypothesis was rejected. Now, however, it may be concluded that the α^p-uplift of land has time and time again been alternately accelerated and retarded by the α^e-factor, and even turned into sinking. These α^e-effects increased towards the centre of the elevation dome in just the same way as the plastic uplift itself. The rising dome pulsated, as it were, under the influence of the α^e-power.

It seems likely that a corresponding development, but with the crustal movements inverse to those of the elevation dome, took place in a zone close outside the zero-isobase. But there, in fact, the law of the Halland diagram is not valid. For the epeirogenic curve of East England—most thoroughly dated both archeologically and pollen-analytically by Harry Godwin (1940)—crosses over the whole system of E-curves derived from that diagram. Evidently, the epeirogenesis of this region was ruled partly by factors which became inessential within the proper area of Fennoscandian land uplift.

To sum up: the frame of Swedish epeirogenic development in Late-Quaternary time is the isostatic-plastic uplift (α^p) through which large areas of present Sweden rose above sea level. Into this frame the chains of α^e-and ω-effects are woven in patterns that vary from tract to tract according to the balance in each case between the three co-operating factors. Among these, α^p and ω have been well-known for a long time; α^e, however, may still look puzzling.

Two facts point to the direction in which the solution of the α^e-problem will, presumably, be found: first, the phenomenon continues, though in a smaller degree, throughout the Post-Glacial warm period, i.e. even since, probably, every remnant of land ice had disappeared from Sweden. This puts any isostatic influence out of the question. Secondly, there is a manifest correlation between α^e-waves and fluctuations of climate. In Södermanland, Florin found that " the Post-Glacial warmer phases, recorded by the vegetation history, correspond to times of shore depression, and the subsequent periods of positive shore displacement . . . According to the pollen diagrams climate deterioration set in when the marine transgressions culminated." The same is the rule for the " transgression shocks " of the Gothi-Glacial and Fini-Glacial, revealed by the Halland shore plane system. Both of these are proved to fit in with horizons in the Late-Glacial pollen diagram of south Fennoscandia, at which the tundra climate seems to have been considerably sharpened. The first of these cold periods was the Salpausselkä epoch of standstill in the recession of the ice front all around Fennoscandia. Furthermore, the alternation between α^e-transgressions and ω-transgressions, mentioned before, still more suggests a correlation between the α^e-phenomena and climatic variations. The ω-transgressions might denote warmer phases of the undulating climate curve, the depressions of which are covered by the α^e-waves of actual land sinking.

The correlation in time between changes of climate and crustal undulations in Scandinavia certainly does not imply causality. Neither phenomenon may reasonably be assumed to be caused by the other. Their co-ordination might, however, demand a common root. A thermal process must be searched for that is able not only to influence the conditions of the atmosphere but even to make the crust vault of the Scandinavian elevation dome alternatively contract and dilate. Contraction and dilatation would explain quite satisfactorily the pulsation of the uplift dome, as described above. Contraction would entail sinking-in of the crust vault, and, correspondingly, positive displacement of the sea shore; dilatation would raise the vault and cause negative shore movement. And each movement would increase in amplitude towards the centre of the elevation dome, just as, in fact, our α^e-effects behave. As a matter of fact, the idea of contraction and dilatation of the earth's crust as cause of changes of level has been suggested before (e.g. the " constriction hypothesis " [Odhner, 1934]).

Now, the final question is where to find a source of heat that could be supposed to affect not only the atmosphere, but even the globe itself, a source powerful enough to cause crustal deformations like those outlined above. An external supply of heat to the globe—from the sun or otherwise—cannot be considered probable; for if it were intensive enough to make the crust react, there would have been a much greater climatic fluctuation during Late Quaternary times than that which actually occurred. To find a possible explanation, we have to turn to the earth's interior. Yet, even such an explanation can only be an hypothetical one. It is one of the chief principles of physical geology of today, one borne out by the whole geological evolution, that heat is not only stored up, but even produced to a large extent, in the interior of the globe. None the less, in spite of an abundant flora of theories, we know, as yet, next to nothing about the nature and manner of working of those thermogenic processes. Are they due to radioactivity, or nuclear fission, or what? They are apparently rhythmic. But can their rhythm be fast enough to answer crustal pulsations of about a millennium in length? There is too ample a space for conjecturing in these matters to attempt even a test of their actual possibilities to explain the α^e-phenomena in the Late-Quaternary epeirogenesis of Fennoscandia. Let me, however, point at the " subterranean fire," though I carefully avoid burning my fingers by it.

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DISCUSSION

F. E. ZEUNER remarked that in Southern Britain the transgression was rhythmic—in the Fenlands, Essex, North Devon—quite universally round the coasts of Southern England. There was a transgression after the Mesolithic, then a slight drop, then a land surface (Neolithic), then a rise to above the present level, then a drop below the present level, then, since Roman times, a further slight transgression. So there was a general eustatic rise (the Littorina transgression), and superimposed minor ups and downs. Since it was difficult to suppose that these were isostatic, some other factor could be presumed.

E. B. BAILEY asked why, if the rise was eustatic in the north of Scotland, it was not also so in the south of England.

F. E. ZEUNER replied that this was a point he had been trying to assess on field evidence. North of the line from the Wash to Bristol the beaches and other interglacial phenomena appeared to be higher than to the south, and they seemed to see the effects of isostatic adjustments. South of the line the terraces of the rivers were adjusted to the same base lines. If there were isostatic movements in the south, they were very small

E. B. BAILEY pointed out that if an area such as Scotland rose, the inflow of material under that area would necessarily alter the level of the surrounding region.

N. G. HORNER, replying to Professor Zeuner, said that the Littorina transgression, referred to in the discussion, had played an important part in Quaternary geology around the Baltic, as had the equivalent oceanic transgression on the Scandinavian west coasts. Whether any " shock theory " was needed for explaining the *Littorina* transgression might still be an open question. As pointed out in Professor von Post's paper, that transgression, which was originally labelled " the great Post-Glacial subsidence," had proved to be, instead, fundamentally a eustatic rise of sea level. Furthermore, what was once considered one single, practically synchronous feature, and accepted as such for approximate or relative dating reference, had turned out to be a complex series of transgressions or oscillations, probably four, spanning a time of at least two millennia.

The question had been studied in all Scandinavian countries, though the displacements of the shore line naturally followed a different pattern in regions with different general intensity in rise of land. The speaker wanted to call attention to the excellent work of the Danish geologists, especially Dr. Johs. Iversen, published in the series of the Geological Survey of Denmark and in the Journal of the Geological Society of Denmark, and elsewhere. Reference should also be made to Knut Faegri's " Studies on the Pleistocene of Western Norway " in the " Arbok " of the Bergen Museum, and, for Sweden, in addition to several papers by von Post, Sten Florin in " Geologiska föreningens förhandlingar," Stockholm, 1944 and 1948.

Another question touched upon in the meeting, as well as during some of the excursions of the Congress, was the possibility of a precise study and interpretation of informative details concerning Quaternary fluctuations of shore level in Southern England. Dr. Godwin, in his Fenland studies, had shown what could be accomplished in favourable regions by a skilful expert. Certain important differences between the Fenland development and that of Scandinavia had just been pointed out in Professor von Post's paper.

The Bristol Channel had also been mentioned. Anyone who took up a detailed study of changes of level in that area was likely to run up against certain complications in addition to those encountered by von Post in Sweden. Minor fluctuations might not, in a region with such a huge tidal range as the Bristol Channel, stand nearly as good a chance of becoming accurately and distinctly registered by nature itself as in areas like those studied by von Post where tide was practically negligible.

STRANDED PLEISTOCENE SEA BEACHES OF SOUTH AUSTRALIA AND ASPECTS OF THE THEORIES OF MILANKOVITCH AND ZEUNER

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Australia

ABSTRACT

A well-preserved series of stranded Pleistocene sea beaches occupies the coastal section of the South-eastern province of South Australia. Younger beaches, with few exceptions, are at progressively lower elevations, in keeping with an inferred over-all progressive decline of Pleistocene sea level.

Fourteen separate sand beaches were formed, and in addition there were three periods of beach inundation due to subsequent excessively high stands of the sea.

Importance is attached to this extensive sea-beach suite as more beaches are present than have been recorded previously along a continental margin beyond the influence of glacial isostasy. There appears to be a striking correspondence between observed beach development and the sea level implications of Zeuner's interpretation of the Milankovitch climatic theory. Statistics detailing the number of high sea-levels (seventeen), the relative beach development and the degree of beach stranding, seemingly provide a remarkably good correlation with Milankovitch's radiation curves.

INTRODUCTION

THE Pleistocene period was an epoch of great fluctuations in sea level. The major oscillations were largely eustatic and agreement is general that they reflected advances and recessions in continental ice-sheets which in turn reflected changes in climate. Also during this period there was an over-all continuous decline in sea level apparently quite apart from glacial eustasy, but the causes of this negative movement are still obscure. In general, therefore, it appears that two major eustatic influences were at work simultaneously during the Pleistocene, and one outstanding effect was the stranding of a series of progressively lower and younger sea beaches each of which represented a particular high sea level stand. In this manner, where Pleistocene sea beaches have been stranded on a relatively stable coast they are thought to be products of the interglacial or interstadial phases of the ice age.

Stranded sea beaches, or benches, of the foregoing type have now been recorded from practically every major coast line in the world. Where the beaches appear to result from purely eustatic movements five major beaches have generally been recorded and less often two or more intermediate ones. In South Australia where conditions of preservation have been unusually favourable, there are seventeen of them and the more obvious of these have been described previously by several authors, principal amongst whom have been Fenner (1930), Tindale (1934 and 1947) and Crocker and Cotton (1946).

Several theories have been advanced to account for the more obvious of these sea level oscillations, or more correctly, for the variations in climate which it is assumed produced them. Prominent amongst these is the theory of Milankovitch in which variations in the amount of solar radiation received by the various zones of latitude are thought to influence over-all climate.

In the present paper, the writer is attempting, not a judgment of the merits of the Milankovitch Theory from the climatological viewpoint, but a comparison of certain theoretical implications with field observations made in South-eastern South Australia. The discussion which follows is based on the fact that there is at least numerical correspondence between the beaches observed and those predicted for the Pleistocene period. For each of seventeen separate high sea levels which can be inferred from Milankovitch's tables, there is an equivalent beach in South Australia. To develop this idea, a brief

description of the stranded sea beach suite in question will be followed by a short summary of the Milankovitch Theory, and then by a comparison of field data with the theoretical implications.

THE STRANDED SEA BEACHES OF SOUTH-EASTERN AUSTRALIA

These fossil sea beaches lie inland from the modern sea coast, from the Victorian border to the mouth of the River Murray, a distance of approximately 200 miles. They occur on a surface sloping gently seawards, which underwent practically continuous downwarping to the north during the period of deposition. In the south (excluding extensive landward sand blows) the beach system spreads over

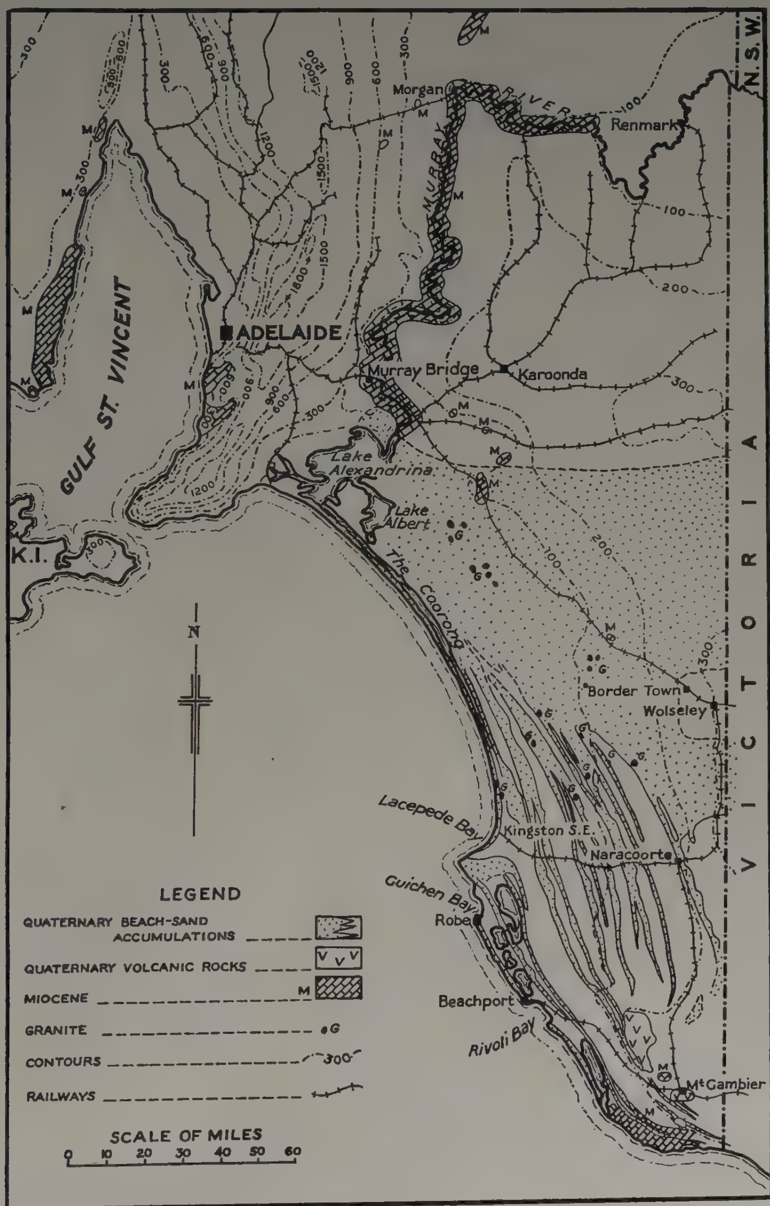

FIG. 1.

Note the tilt, downwards to the north, of the stranded beaches. This negative movement is complementary to positive movements of the Mount Lofty " horst " range near Adelaide.

a width of 60 miles, but to the north, due to the downwarping movements, the dunes coalesce and lose their identity (Fig. 1).

This beach system is one of the most complete and best preserved of the Pleistocene continental suite anywhere in the world. An unusual set of circumstances operated to stabilize and " fossilize " the beach deposits very rapidly and to protect them from significant erosion. In particular, colonization by vegetation, the production of travertinous soil profiles under semi-arid conditions and the virtual absence of surface drainage were prime factors.

The area is underlain for the most part by mid-Tertiary bryozoal limestones and fluviatile sands which conduct a big proportion of the surface waters to the sea by subterranean channels.

Of the sea beach system itself, fourteen major beach-ridged associations can be recognized readily from aerial photographs and topographic maps and in the field, and each is orientated sub-parallel with the present sea coast. Each association may include twenty or more separate beach ridges within its mass, and these may have great linear persistence. The respective beach ridge associations may be a mile or more in width and be separated from their neighbours by marshy flats frequently several miles wide. The deposits are mostly consolidated wind-sorted beach sands (aeolinanites) showing typical " sand avalanche " structures, and in section the dunes display a complexity of fossil soil horizons. (Travertinous " B " horizons.)

With the exception of the youngest beaches the dunes appear to be simple, that is, they have not suffered subsequent marine submergence. Of the exceptions, the older or Woakwine dune range has been truncated twice by marine agencies since consolidation, with the establishment of marine reef faunas on the eroded aeolianite surfaces. Later during the *Anadara* (=Arca) or " twenty foot " stand of recent times, the sea flowed in around the Woakwine (and Dairy) Ranges again. The youngest exception—the Robe dune—apparently also underwent partial submergence during the *Anadara* stand and after a small retreat, the sea has again advanced sufficiently to drown its base.

Concerning the actual extent of stranding of the various sea beaches, in relation to modern sea level, only approximate determinations are yet possible, due to the absence of reliable restricting criteria. Until such criteria are available, flat and marsh levels immediately confronting the respective dunes will continue to be used to represent fossil sea level approximately, particularly as much accurate survey data of this type are already available which can be related to present Low Water Ordinary Spring Tides at Robe.

A further complication of greater significance in beach measurements relates to the degree of northward tilt away from the Mount Gambier—Mt. Graham volcanic areas (or conversely towards the Murray River Mouth). With two minor exceptions (which the author relates to recurrent volcanic activity) this downward movement to the north was continuous throughout the Pleistocene period. In all probability it was complementary to the uplifting of the Mount Lofty " horst " range (See Fig. 1) near Adelaide.

In the case of the oldest beach (Naracoorte), the downwarp is 50 feet over a distance of only 60 miles and about 200 feet in 200 miles. Obviously random levels along the courses of the dunes could have little significance and in the present paper a series of fore-dune flat levels on a line from Robe to Naracoorte (approximately at right angles to the strike of the beaches) has been selected for purposes of dune correlation (See Fig. 2). This line of section is considered to lie sufficiently far from the volcanic area to be not too severely affected yet giving a good altitudinal separation of the beaches. The maximum altitude of the highest beach is 230 feet.

THE MILANKOVITCH CLIMATIC THEORY

According to this theory, fluctuations in the amount of solar radiation received by any particular locality or zone of latitude of the earth's surface (or rather its upper atmosphere) can be caused by changeable elements in the earth's orbit, called *inequalities* or *perturbations*. These have periods of many thousands of years. They do not alter the total amount of radiation striking the earth, but they are considered to have an effect on the relative intensities and durations of the seasons.

The major perturbations referred to are respectively:

(1) The obliquity of the ecliptic.

(2) The eccentricity of the earth's orbit, and

(3) The precession of the equinoxes.

These variables fluctuate with periods of 40,000, 92,000 and 21,000 years respectively.

Using these factors, astronomers have constructed tables and curves for the amount of radiation received by the various degrees of latitude of the earth. Of these, the Tables of Milankovitch (1938) appear to be most satisfactory. It is, of course, inevitable that complications exist which introduce errors into the calculation, and due to these, the tables are of little practical value beyond about one million years before the present.

With this type of data, attempts have been made to account for the various glacial phases of the Pleistocene, although it is realised that it cannot explain the ice age in itself. The astronomical theory then is thought by some workers (particularly Zeuner) to indicate the underlying causes of glacial and inter-glacial phases within an ice age, the former being regarded as due to periods of high winter radiation and low summer radiation and the latter by periods of low winter radiation and high summer radiation. For the present purpose, only the summer radiation need be discussed, as winter radiation displays an almost exact inverse relation.

The Milankovitch curves (see lower part of Fig. 3) reveal a series of maxima or minima at intervals of a few tens of thousands of years. Some of the maxima or minima are more intense than others and Zeuner (1946) and other workers have suggested that a grouping of stronger minima may correspond with a glacial phase within the ice age and consequently also with a period of generally lower sea level.

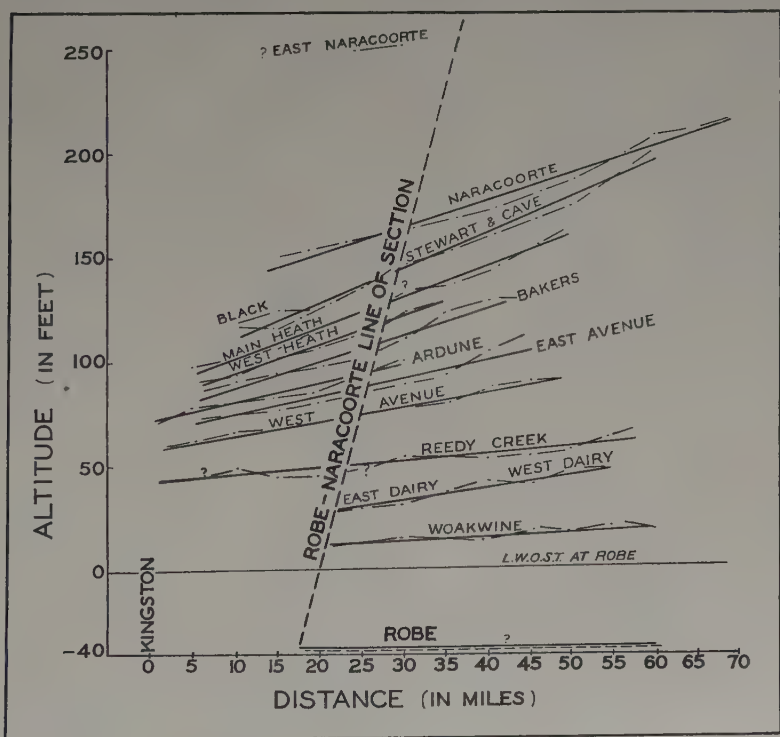

FIG. 2.

The general progressive *north* tilt-down of the south-eastern sub-coastal land during the period of beach formation is clearly demonstrated in this diagram. The relative *south* tilt-down apparent between deposition of the Naracoorte and the Stewart and Cave beaches and between the Reedy and Dairy beaches is almost certainly closely related to the two volcanic outpourings in the Mount Gambier district.

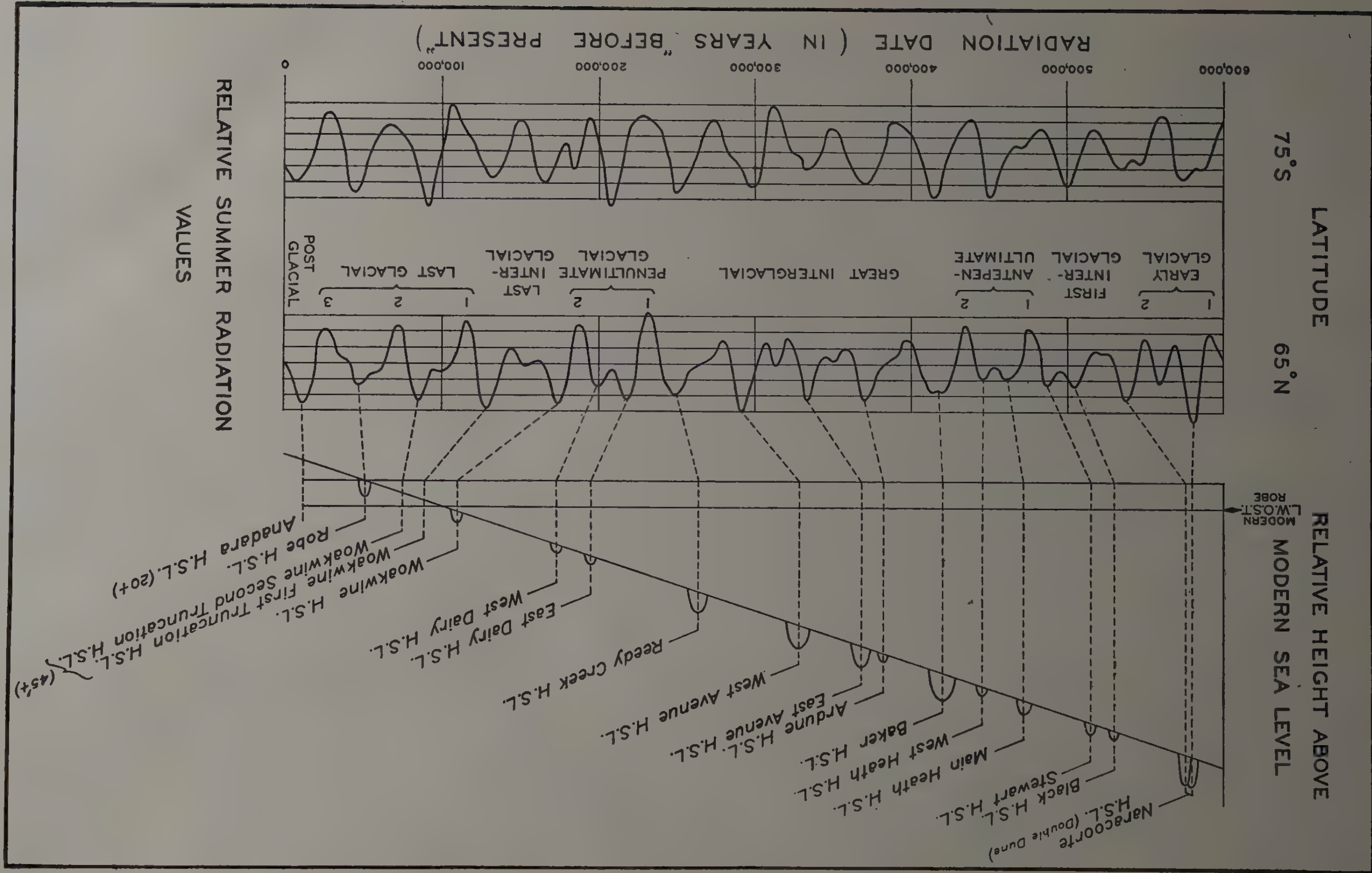

FIG. 3.

An attempted correlation of Pleistocene stranded sea beaches in the south-east region of South Australia with periods of high summer radiation on two of the " controlling " curves of Milankovitch. In the upper portion of the diagram, the relative altitudes of the respective beaches (taken from the Robe-Naracoorte line of Section in Fig. 2) are plotted on an arbitrary sloping line representing theoretical decline in sea-level for the duration of the " Pleistocene " period. The relative importance of the respective beaches has been illustrated diagrammatically from information based on the widths of the respective beach deposits. In attempting the matching it is remembered that the curve for 75 degrees S. latitude is considered to have only about one quarter the influence on sea level of that for the northern hemisphere.

Developing this idea a little further it would appear that successive maxima may each be correlated with periods of high sea level. If such was the case, a complexity of high sea level beaches could be anticipated in the field, and as stranded sea beaches are common to many coasts here may be one of the better tests for the theory. However, before attempting such matching several difficulties should be appreciated.

One complication concerns the phenomenon of *retardation* which may be defined as the retardation of ice front retreat due to absorption of heat in the melting process. This will result in the true age of a glacial phase maximum being somewhat less than that of the corresponding summer radiation minimum. The error, however, is relatively small for earlier phases, and according to Zeuner (1944) is probably less than 12,000 years for the last glacial (based on de Geer's varve counts for the southern Swedish moraines). Consequently, sea level changes will be influenced similarly.

A further complication arises which is of particular importance in discussions involving sea level variation. Milankovitch's tables show that minima and maxima of summer radiation change their positions on the time scale slightly with geographic latitude, while amplitudes vary considerably more. For this reason it is necessary to consider the zone of latitude in which a particular glaciated area is situated. For example, maxima affecting the bulk of various glaciers in the northern hemisphere may pre- or post-date maxima in the southern hemisphere by several thousand years. In this way, maximum water capture or release caused by ice formation or melting in each hemisphere may not coincide, with the result that the overall rises or falls of sea level are reduced somewhat. As indications of this non-coincidence of respective maxima and minima the summer radiation curves for latitudes 65°N.* and 75°S. (see Fig. 3) are instructive. These two curves are thought to be largely responsible for major glacial control in the northern and southern hemispheres respectively. It is also seen that, although the maxima and minima of the curves show sensibly close correspondence in time, their respective amplitudes vary very considerably, suggesting an amount of " averaging out " in effect.

Sea level rise consequent upon deglaciation to the present extent after the last glacial phase (exclusive of the effects of plastic deformation of the earth's crust) is considered (Daly, 1934; Zeuner, 1944, etc.) to be 280 to 330 feet (85 to 100 metres). Of this Zeuner considers only about 13 to 17 per cent to be due to Antarctic ice, and as there were no other great ice sheets south of the equator, the climatic history and sea level variations of the Pleistocene were dominated by events occurring in the northern hemisphere. It appears, therefore, that fluctuations in the summer radiation values for 65°N. (and associated latitudes) may bring about sea level changes of up to say 250 feet (approximately 75 metres) while those due to Antarctic variations (e.g. 75°S.) less than 60 feet (approximately 20 metres).

Keeping these relationships in mind, it seems that by superimposing the two " controlling " summer radiation curves there may be a method of gauging probable sea level trends more accurately for the period concerned.

PROBLEMS OF THE APPLICATION OF THE CLIMATIC THEORY

As pointed out previously, the best method of testing a theory of this nature would be by attempting to match predictions against field evidence. This has already been done to a considerable extent by Zeuner, particularly concerning phases of glaciation, but also to a lesser extent with high sea level stands. Where glacier advances and retreats are concerned much valuable evidence is destroyed by subsequent advances and anything approaching a complete matching may be difficult or impossible. However, this method seems already to have met with a certain amount of success.

Where successive high sea level stands are to be considered there seems to be more hope, especially as sea level has apparently declined continuously during the Pleistocene. Stratigraphical evidence

* Zeuner, 1944, p. 170, has noted that " For the Scandinavian area . . . the curve of summer radiation for 65° N. has been most widely used. This is the latitude of the northern part of the Scandinavian mountains where the glaciating process is likely to have started. The differences in the curves for 65°, 55° and 45° N. are small and for the most purposes insignificant ,and the phases of the alpine glaciations can be dated by means of this curve also."

indicated that over the period of the last 600,000 years (since the beginning of the Pleistocene) the sea level has fallen (due to causes other than glacial eustasy) by 70 metres, or an average of approximately 1/10 mm. annually (R.A. Daly, 1934). On this assumption each younger interglacial or interstadial (i.e., warm intervals during actual glacial phases), if of approximately comparable intensity, would result in a stranded beach successively lower than its predecessor, and in this manner high sea level beaches would be stranded beyond tide reach unless negative coastal land movements were at work. Under favourable conditions, beaches representing all important interglacials and interstadials from the beginning of the Pleistocene should be preserved. Further, if a favourable land surface remained stationary for the duration of sea level decline, more accurate information as to the relative duration of high sea level stands and also to the actual relative sea level altitudes, would be available.

Now, assuming that a correlation of this sort is possible, the question arises as to how to get specific matchings. Some assumptions are necessary. The South-eastern province of South Australia is essentially a seaward sloping plane, with gentle relatively even overall gradients. If no large scale negative or positive land movements have taken place during the Pleistocene period, the vertical spacing of the beaches should be a function of the time interval between the interglacial high sea levels, as it has already been pointed out that there was an overall continuous drop in sea level during the period.

It is assumed further that all glacial ice, other than that of the massive Greenland and Antarctic nuclei, melted during the more severe interglacials and interstadials, so allowing establishment of relatively (eustatically) stable beaches, and that in general, with a relatively stationary sea level, the greater the period of still stand, the greater the dune accumulation. As a corollary of this, it would seem that on an exposed coast, the mass (and to a lesser extent the width) of a dune range or terrace would be a function of the intensity or duration of a high sea level stand.

In attempting a matching of the geological evidence with the radiation curves, it is stressed once more that the curve for 65°N. is a major control with assumed maximum sea level influence of up to about 250 feet, whereas that for 75°S. brought about changes up to less than 60 feet. The northern hemisphere influence will therefore very largely mask that of Antarctica. Where their respective maxima coincide, effects on sea level will be greatest for these influences, and where maximum of the one corresponds with the minimum of the other there will be a consequent reduction in effect on sea level.

THE LOCAL TEST OF THE THEORY

In Fig. 3 the summer radiation curves from Milankovitch's tables for 65°N. and 75°S. (after Zeuner 1944 and 1946 respectively) are given for the last 600,000 years. The sloping line above these curves represents the assumed even decline of sea level for the Pleistocene Period, and upon it are imposed the stranded beaches at their estimated altitudes above present sea level in the Robe area. The two Woakwine " truncation " high sea levels and the *Anadara* high sea level are purposely displaced to the right from their true altitudinal positions to give a more realistic relative age relation. The relative importance or intensity of the high sea level stands of the respective beaches is illustrated diagrammatically from information based on the average width of the respective dunes.

The curve for 65° N. is considered by Zeuner to cover the period of the Pleistocene from the commencement of the Early Glaciation to the present. Its backward continuation to one million years, in so far as it is reliable, indicates no very significant associations of low values which may be indicative of widespread glaciation. The low point on the curve indicating a radiation minimum 590,000 years ago has therefore been interpreted as the first phase of the early glaciation. Subsequent glaciations representing antepenultimate (476,000 and 435,000 years before the present) penultimate (230,000 and 187,000 years before the present) and the last (115,000, 72,000 and 25,000 years before the present) advances can be deduced at intervals along the curves.

Conversely the high points on the curve should be associated with the high sea level phases, both of the glacial interstadials and of the interglacials. It is also noted that the glacial phases and high sea level contributions of the southern hemisphere (as indicated on the curve for 75° S.) show no exact correspondence with conditions in the northern hemisphere.

In applying the theory, two simple approaches are available which should facilitate specific matching if such is possible. They are:—

(1) Correlation of the last high sea level with the latest radiation maximum and relating progressively older high sea levels to preceding radiation maxima.

(2) Assuming that the first " Pleistocene " high sea level followed the first continental glaciation inferred at 590,000 years before the present and working forward along the curve.

The first method is simpler and gives a remarkably close match of field evidence with theory (Fig. 3).* The oldest beach (Naracoorte) comes to correspond with the first high sea level of the first interglacial, which is, of course, reasonable.

In applying the second method, attention is directed to the fact that the appearance of *prominent* sea beaches (there is a doubtful one at a higher altitude) in the South-east province marks a very new phase in the marine environmental history of the area which may well mark the commencement of the Pleistocene period.

As far as can be judged at present, the upper Pliocene shore line in this region was irregular, marked by open-beach shell banks and an irregular system of estuaries and bays. Quite sharply these conditions gave way to well marked sandy beaches backed by continuous and massive dune accumulations. Such a rapid change could be explained by postulating a temporary retreat of the sea, followed by an advance which swept sand from the freshly exposed portion of the continental shelf to build the first *large* coastal dune. Just such a sequence of events could be anticipated with the onset of marked glacial eustasy; as each eustatic rise in sea level followed each glacial phase, additional quantities of continental platform sands would be carried back to the limit of the new high strand level which in each successive case would be somewhat lower due to the " declining sea level " factor.

In developing this theory the first Pleistocene high sea level would be correlated with the radiation maximum at 580,000 years before the present.† Subsequent matching on this basis at first sight presents a difficulty as there would appear to be one or two beaches too few. However, this difficulty is probably resolved by the fact that the Naracoorte (or first) beach is compound (see Fig. 1). The separate beaches could be equated with the radiation maxima at 580,000 and 538,000 years before the present respectively. There is no sign of a minor high sea level equivalent to the radiation maximum at 559,000 years B.P. Assuming this solution to be correct, subsequent matching would be essentially the same as for the first method.

Referring now to the complete matching, the results are almost suspiciously good. The Naracoorte dune is well developed and/or compound as anticipated, and the Black and Stewart dunes are small and altitudinally closely related. The Heath ranges are similarly poorly developed as would be expected, while the succeeding Bakers range is much stronger. The Ardune range is weaker than anticipated and the East Avenue range rather stronger. West Avenue and Reedy Creek ranges correlate satisfactorily. In comparison with the development of the 65° N. curve only, the East Dairy range is poorly developed, but the corresponding low radiation value of the 75° S. curve at this point indicates a possible explanation. The Antarctic area would be in a more severe glacial phase, weakening the effect on sea level of northern hemisphere deglaciation. The West Dairy range is suitably weakly developed.

The Woakwine range, next in the succession, has had a complex history. Its earlier development probably satisfied the radiation maximum relationships at about 175,000 years before the present

* It is to be remembered that the influence of glaciation in the southern latitude on sea level is considered to be only one quarter to one fifth of that in the northern hemisphere.

† Unless otherwise stated the radiation maximum dates quoted refer specifically to the curve for 65° N.

very well. Subsequently however the Woakwine dune was truncated at least twice by marine agencies allowing the establishment of reef faunas. On each occasion a fall in sea level followed, allowing travertinization of the reef shell-bed and further accumulations of shell sand on the older range remnants. Only a negative fall in the sea level, a temporary halting of " overall " sea level decline or a more complete melting of continental ice than in the original Woakwine phase, could bring about such a sequence of events. It is just possible that the latter did operate (see relative intensities of nodes on the two curves between 180,000 and 80,000 years before the present) causing temporary drownings of the range. However a very open mind must be kept on this problem as two high sea levels at least 40 feet in excess of the *original* Woakwine beach must be explained.

The only remaining dune association to be accounted for is the Robe range. The radiation maximum at 42,000 years before the present satisfies the moderately well-developed character of this aeolianite system. The Robe high sea level was followed by a prominent radiation minimum which is generally correlated with the Pre-Flandrian regression. This is in keeping with field evidence at Robe. The

TABLE I

General Correlation	Phase	Stranded Beach	Radiation Date (In years Before Present)	
Early Glaciation	E. Gl. I		590,000	
	H. S. L.	(?) Early Naracoorte		580,000
	E. Gl. II		550,000	
First Interglacial	H. S. L.	Naracoorte		538,000
	H. S. L.	Black		504,000
	H. S. L.	Stewart		483,000
Antepenultimate Glaciation	Ap. Gl. I		476,000	
	H. S. L.	Main Heath		460,000
	H. S. L.	West Heath		445,000
	Ap. Gl. II		436,000	
Great Interglacial	H. S. L.	Baker		425,000
	H. S. L.	Ardune		370,000
	H. S. L.	East Avenue		330,000
	H. S. L.	West Avenue		294,000
	H. S. L.	Reedy Creek		249,000
Penultimate Glaciation	P. Gl. I		230,000	
	H. S. L.	East Dairy		210,000
	H. S. L.	West Dairy		200,000
	P. Gl. II		187,000	
Last Interglacial	H. S. L.	Woakwine		175,000
	H. S. L.	First Truncation H. S. L.		130,000
Last Glaciation	L. Gl. I		115,000	
	H. S. L.	Second Truncation H. S. L.		83,000
	L. Gl. II		72,000	
	H. S. L.	Robe		44,000
	L. Gl. III		25,000	
Post Glacial Phase (Recent Period)	H. S. L.	Anadara or "twenty foot" H. S. L.		10,000

NOTE. H. S. L. = High Sea Level

original Robe range was stranded sufficiently long to allow travertinisation of the range before the sea level rose once more.

With this final rise of sea level following Pre-Flandrian regression the Pleistocene period is considered to have ended, although of course, such an assumption is chiefly a matter of convenience. The sea rose considerably and exceeded its modern stand by about 20 feet as the *Anadara* high sea level which is evidently correlated with radiation maximum 10,000 years before the present. According to the radiation curves, the modern sea level should be now falling, but although a negative eustatic movement has occurred since the *Anadara* stand, at present the trend is again slightly upward or stationary. Such a contrary trend may be due to other more minor complicating factors.

The partial submergence of the Robe and Woakwine Ranges by the *Anadara* high sea level raises some difficulties. There appear to be no significant associations of radiation maxima which may cause a large relative sea level rise sufficient to swamp earlier high sea level beaches; other than by postulating a recent negative movement of the land, only the arresting of the general Pleistocene decline of sea level or its reversal could be responsible. Evidence does suggest a late subsidence of the land locally but this was largely *Pre-Anadaran* as the latest or Recent " 20 foot " stand of the sea is Australia-wide, probably world-wide, and therefore almost certainly eustatic. A geochronology for the South-eastern beaches which summarizes the fore-going discussion is given in Table I.

CONCLUSION

Using certain simple assumptions a good correlation can be made of the 14 successive Pleistocene stranded beaches and three marine floodings of the South-eastern province of South Australia with maxima of the summer radiation curves for 65° N. and 75° S. (combined). Theoretically these curves provide a major control on phases of the development of ice-sheets in the northern and southern hemispheres respectively. It would seem improbable that such good correlation would be purely fortuitous.

In attempting such direct matching, the writer is aware of certain dangers. It is obvious that much depends upon the accuracy or otherwise of the Milankovitch curves themselves, and upon their climatological significance. However, whether the Milankovitch curves prove unreliable or not, the field evidence cited would lead one to anticipate a comparable curve to be applicable.

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DISCUSSION

E. B. BAILEY welcomed the evidence from Australia and said he was impressed by the manner in which the factors had been considered, especially those controlling the preservation of the dunes; the field evidence had been traced out in a most beautiful manner.

F. E. ZEUNER said he had been greatly impressed. The author had described an extraordinary number of beaches. The speaker was unable to remember any other area in the world with such a complete series. For comparison hinge-points were needed. One was the present day, and it was necessary also to fix the beginning of the series. In the Pliocene—if he might be permitted to use that term—there was a regime of very shallow seas and a long period of rest. From a certain moment onwards a period of stronger fluctuations set in. There was a Pleistocene drop of 100 metres

in the Atlantic and the Mediterranean. This was correlated on reasonable evidence with the first interglacial. In South Australia—this was all speculation—the same thing could be seen. The first ridge corresponded to the first high sea level. So ridge No. 1, might represent Milanzian sea level elsewhere, with 15 phases of high sea level from then until the present. In the Mediterranean, 5 or perhaps 7 were known, though admittedly there might be more (negative evidence was difficult to assess).

The speaker continued by considering the correlation with the radiation curve. The high sea levels were correlated with high summer radiation. The radiation curve gave the maximum number possible. There were 17 on the curve; Dr. Sprigg had about the same number. That agreement should be noted.

N. G. Horner said that respect and admiration for Dr. Sprigg's most comprehensive and careful study, which had clearly established such interesting field facts, might still leave room for doubt about the interpretation of those facts. When finding what seemed a complete correlation between the remarkable succession of ocean beaches in South Australia and the radiation curve of Milankovitch, and when suggesting the possibility of a causal relation, Dr. Sprigg wisely stressed the conjectural character of the combination. It seemed difficult to understand why the Australian shore features should span just the time that Milankovitch had chosen to include in his computation. If his curve really corresponded in time to the Quaternary glaciations and contained their explanation, and even with due consideration of the glacio-eustatic factor, there still remained the question of why the preserved beaches of southern Australia should begin just in connection with first glaciation.

Experience from other parts of the world, though involving a much shorter time, had shown how easily an interpretation founded mainly on morphological shore features without sufficient support of other evidence could lead one astray, especially when dating was concerned. It would be interesting to learn more about the fauna and flora related to the different sea levels, if convincing relations could be established. A further study of secondary morphological changes and of the progress of soil formation with increasing age of the beaches would also be of interest. Even allowing for doubts about the complete correlations between beaches and radiation—and provided instability of land had not complicated the picture more severely than the paper led one to believe—Dr. Sprigg had added another indication, to those already collected from different parts of the world, of a progressive sinking of ocean level in Pleistocene time, in itself a problem of far-reaching geological consequence.

R. C. Sprigg said that with regard to fossil evidence for the Pleistocene ages of the beaches, there were definite difficulties. Firstly, no reliable horizon indicators were yet known which could give specific correlations. The oldest beach (Naracoorte) in the north apparently in part overlay massive marine shell banks, thought to be late Pliocene in age. However, the speaker wished to point out that, even though such evidence was in keeping with his views, there was still far too much indefiniteness in our knowledge of the age correlations of many Australian late Tertiary and ? Pleistocene deposits. Moreover, much confusion had been added to Pleistocene and Recent problems by the great environmental and ecological variations so characteristic of those times. The percentage of extinct species in a given population, for example, had little meaning. The environmental variation from a glacial phase to a warmer (high sea level) phase, representing say a period of 10,000 years, might be much greater than between two high sea level phases separated by many tens of thousands of years.

As for physiographic evidence on the antiquity of the beaches, the speaker said that he was dealing with that question more adequately in another publication. In the foregoing paper he had stressed the excellent preservation of the dunes. In a relative sense they were beautifully preserved, but it was to be noted that, whereas beach ridging was so prominent on the latest dune complex, it became progressively weaker (due to sand drifting and erosion) in earlier ones. In the oldest beaches such ridging had almost disappeared. In most dunes soil profiles had been stripped and the A horizon (podsolized sand) was usually redistributed to the lee of the dune. Many dunes showed a complex of old soil profiles (travertine layers) and in many cases the formation of those travertine sheets had been a dominant factor in dune preservation.

It was obvious from the enormous beach accumulations present in the province that the dune system was not just a product of a very short period such as that represented by the last high sea level retreat. Each stranded beach might be up to several miles in width and 150 ft. in height. Obviously such a volume of sand could not accumulate in a few tens of thousands of years. Further, the presence of continuous and massive inland sand blows (see Fig. 1) more than 200 miles long and 100 miles wide was not a short term phenomenon.

Replying to a question about truncations of earlier formations, Dr. Sprigg said that there could be little doubt that marine truncation did occur. The original deposits of the Woakwine beach were open ocean *sandy beach* type. Later deposits within the dune indicated marine truncation of *consolidated* dune rock and the establishment of typical *reef* shell faunas at least 40 ft. above the original strand level.

On the flats inland from that dune, as a result of repeated flooding, one must expect a complex of marine deposits. So far only two marine deposits had been positively identified post-dating the Dairy beaches, whereas there should have been three. When more work had been done, the speaker hoped to be able to point to the third. Unfortunately, the most modern high sea level (Anadara) was one which flowed around the base of the Woakwine Range and consequently its deposits masked much of the earlier evidence.

C. A. Fleming enquired whether the " Pliocene " deposits underlying the dune suite were correlated with the Werrikooian stage in the Australian marine sequence. If so, there was strong evidence of cooling of glacial intensity in

New Zealand at a time considerably before the Werrikooian, which would indicate that the earliest of the South Australian dunes were not as old as earliest Pleistocene.

R. C. SPRIGG replied that Dr. Fleming had raised a very debatable point. At present the whole question as to the age and correlation of the Werrikooian was in the melting pot. If the speaker's memory served him reliably, the Werrikooian was thought to be very late Pliocene or earliest Pleistocene. Information which he had collected recently in co-operation with Dr. B. C. Cotton of the South Australian Museum, while working on submarine bores in Robe Harbour, suggested a much more recent age for those so-called Werrikooian deposits.

Regarding cold phases in the lower Pliocene sediments, the speaker said that he knew nothing of such developments in South Australia, although detailed research was going forward on them at the present time. The problem was extremely interesting and one upon which he looked forward to hearing a great deal more.

QUELQUES CONTRIBUTIONS GÉOLOGIQUES SUR LE TIMOR PORTUGAIS

Par A. SOUSA TORRES et J. PIRES SOARES

Portugal

RÉSUMÉ

En 1912, un ingénieur portugais, M. H. Mascarenhas Inglês, et, plus tard, son collègue Artur do Canto, alors aussi à Timor, ont fait " sponte sua " des recherches géologiques.

Ils recueillirent là-bas quantité d'échantillons, indicateurs de quelques-unes des formations y dominantes et qui fûrent, successivement, mises en évidence par les travaux systématiques de géologues hollandais, allemands, australiens, américains, etc.

De notre connaissance, cependant, ces récoltes ont été les premières dues à des Portugais qui, sur place, s'occupèrent de la géognosie de notre province timorense.

Voici pourquoi, en hommage à ces devanciers, nous avons pris le soin d'étudier les matériaux ainsi obtenus et de, sur un tel documentaire, présenter un rapport, aussi détaillé que possible.

LES premières études géognostiques, faites par un scientiste portugais, à Timor sont dues à l'ingénieur H. Mascarenhas Inglês qui, en 1914 et 1915, y a recueilli un bon documentaire, sur les formations pas encore connues, sous le point de vue chronologique. Plus tard, un autre ingénieur, Artur do Canto, prenant Aliambata pour centre de son activité de camp, a aussi fait une excellente récolte d'échantillons géo-minéralogiques, dont la provenance fut indiquée dans un schéma. Celui-ci est la seule pièce (dit-on), du dossier scientifique de Canto, échappée au pillage des troupes japonaises, pendant leur occupation de notre Timor; d'où heureusement les bons échantillons étaient déjà sortis vers Lisbonne, depuis longtemps.

Les matériaux, réunis par ces deux devanciers portugais, comprennent une grande diversité de roches et de fossiles, le tout se rapportant à des formations paléozoïques, mésozoïques et cénozoïques. En outre, c'est curieux de constater que l'ingénieur Inglês avait déjà, en 1914, découvert, au Timor portugais, le temoignage de l'Ordovicien (Silurien inférieur).

L'étude de nos échantillons timorenses nous a fait admettre qu'ils représentent les formations géologiques suivantes :—

L'ARCHAÏQUE indiqué par: une série lithologique: Mica-schistes (sensu lato):—Mica-schistes gneissiques plissés en rides profondes, mica-schistes régulaires; chlorito-schistes; sericito-schistes; phyllades calcarifères; paragneisses et quelques serpentines. Ce classement pourra-t-être valable, jusqu'à ce qu'un service régulier, géologique, pour lever une nouvelle carte, soit établi dans notre province timorense.

L'ORDOVICIEN mis en évidence par: Des grès pyriteux à *Arthrophycus* cf. *harlani* Hall, *Asaphus tyrannus* Salter (fragment sur du schiste brun-foncé); des schistes ardoisiers; des grès schisteux, calcarifères; des grès hématiteux ("type lie-de-vin"); des schistes micacés, très fins, identiques à ceux de *Didymograptus murchisoni* Beck; des grauwackes, finement granulaires, alternantes avec des lits de schistes précédents.

L'ANTHRACOLITIQUE dévoilé par: *Schizoblastus timorensis* Boehm, *Spirifer rajah* Salter, *Rhynchonella* sp., *Modiola* cf. *lidarensis* Diener, et *M. problematica* Diener.

LE TRIASIQUE prouvé par: *Pachypora intabulata* Wanner, *Retzia humaica* Bittner, *Avicula* cf. *girthiana* Bittner, *Amonotis* cf. *rothpletzi* Wanner, *Halobia* cf. *comata* Bittner, *Halobia* cf. *molukana* Wanner, *Daonella lommeli* Wanner, et *Atractites* sp.

LE JURASSIQUE témoigné par: *Montlivaultia* cf. *numismalis* d'Orb., *Terebratula* aff. *pala* Quensdt., *T.* (*Waldheimia*) aff. *carinata* Lamk., *T.* cf. *insignis* var. *maltonensis* Oppel, *T.* cf. *fileyensis* Walker, *Burmirhynchia subglobosa* Buckman, *Schlotheimia* sp., *Harpoceras* sp., et *Stephanoceras* cf. *dimerum* Waagen.

LE CRÉTACIQUE INFÉRIEUR indiqué par: *Hoplites* cf. *angulicostatus* d'Orb.

FAUNE CRÉTACIQUE, SUPÉRIEURE, ET FAUNE DE TRANSITION POUR LE NUMMULITIQUE:—*Arca* aff. *moutoneana* d'Orb., *Cardium* cf. *protosubrugosum* Noetling, *Cheliconus* aff. *ventricosum* Gmelin, *Cyprina* cf. *quadrata* d'Orb., *Lima* aff. *squamosa* Lamk., *Pecten subplicatus* Sow., *Trochus* aff. *subcognatus* d'Archiac et Haime, *Trochus* cf. *cumulans* Brongniart, *Gibbula* cf. *Jerdoniana* Stoliczka, *Ovula* cf. *ellipsoides* d'Arch. et Haim., *Cypraea* (*Aricia*) aff. *amygdalina* Brocchi, *Eocypraea* aff. *cotteri* Cox, *Columbella* cf. *tiara* Bon, et *Phyllacanthus* (*Leiocidaris*) cf. *imperialis* (Lamk.).

NÉOGÉNIQUE indiqué par: Plusieurs moulages de *Venus*, *Pleurotomaria*, *Terebra*, *Cypraea*, *Arca*, *Spondylus*, etc.

À la suite de cette note préliminaire, une autre note paraîtra sur notre collection pétrologique de Timor. À ce propos, nous remercions vivement M. le professeur Assunção, qui a bien voulu nous communiquer les résultats de son étude sur les échantillons venus de l'enclave d'Ocussi: péridotites, andésites à olivine et bronzite, serpentines à antigorite et crisotile, tufs volcaniques, renfermant des fragments de basalte, phénocristaux de augite et de bytownite.

Finalement, nous rendons à M. le Général Sequeira Varejão l'hommage de notre reconnaissance à cause de ses précieuses indications cartographiques sur le territoire du Timor portugais.

Nous adressons aussi à l'ingénieur Cinatti l'expression de notre remerciement, car il nous a apporté des échantillons de roches timorenses maintenant offertes au Musée géologique de la Faculté des Sciences de Lisbonne.

FLOWAGE STRUCTURES AND ORE DEPOSITS OF THE CALEDONIDES OF NORWAY

By T. VOGT

Norway

ABSTRACT

The longitudinal axes of ore bodies, especially of epigenetic pyrite deposits, are found to be conformable to the flowage structures of the surrounding metamorphic rocks, largely mica-schists. The mentioned structure is a mineral structure, the longitudinal axes of mineral grains, as biotite flakes, feldspar crystals, hornblende needles etc., representing the direction of the flowage. The mineral structures may be combined with styloid structures or not. Axes of minor folds do not in general coincide with this structure, except, in some areas, in regard to a special type of compressional folds. The structure lines of flowage have been mapped by the author in several areas. The lines generally occur transverse to the direction of the Caledonian mountain chain. This is especially pronounced for the more peripheral parts of the Caledonides. In the author's opinion, the flowage structures display the plastic movement of the rocks largely from the central to the peripheral (eastern) part of the mountain chain, the rocks flowing, and the crystals growing, in the direction of the minor component of pressure. Discrepancies between the conditions in the Alps and in the Caledonides may depend upon the different depth of their rocks during the tectonic movements.

A LONG time ago, in Norway, Hans Reusch (1888) clearly pointed out the conformability of the axes of ore bodies and the stretching of the surrounding rocks. From Western Norway he described three ore deposits, the Jernsmauget iron mine and the Varaldsøy and Vigsnes pyrite mines, the ore axes of which were parallel to the styloid structures of the adjoining rocks. The dip of the stretching was steep in all cases. These important observations were practically forgotten, the conformability of the ore axes and the folding axes of the rocks being emphasized by later Norwegian authors.

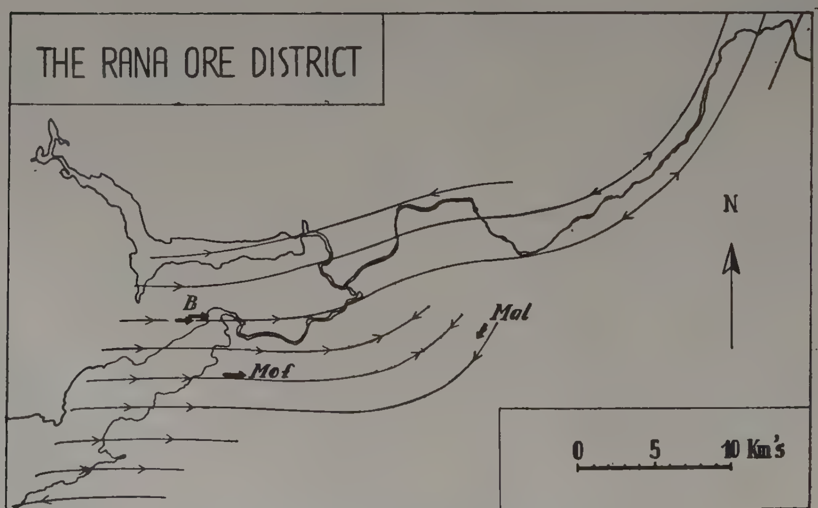

FIG. 1.—*Part of the Rana ore district.*

Thin continuous lines represent the flowage structure; short thick lines are axes of pyrite deposits. Arrows designate the dip of the flowage structures and of the axes of ore bodies. B = the Bossmo mines. Mof. = the Mofjell mine. Mal. = the Malmhaug mine.

Especially during the last ten years the present author has studied the flowage structures in a great many areas mostly with epigenetic pyrite deposits in the Caledonides of Norway. Everywhere the axes of the ore deposits were conformable to the lines of flowage of the surrounding rocks. The axes of the larger folds were wholly independent of the flowage structures. The axes of minor folds may or may not be conformable to the flowage structures and to the axes of the ore bodies. This depends on the tectonic type of the area in question.

The flowage structures were observed on the foliation planes, mostly of mica-schists or phyllites, and also of minor intrusive bodies in the sediments. They may in some cases be developed as obvious styloid structures, and are then mostly accompanied by minor foldings with axes conformable to the stretching. In most cases, however, the flowage structures were less obvious, being then a pure crystal flowage, the foliation planes also being level and smooth. Biotite flakes observed under a magnifying glass may have the longer dimensions in the direction of the flowage. The same may be the case with pyrrhotite and other mineral grains. And, of course, parallel hornblende needles are arranged in the direction of the flowage. Fairly perpendicular to the direction of the flowage, a fine rippling often occurred. A conclusive criterion as to the direction of the flowage lines was in all cases the crystal flowage and, perhaps, especially the elongation of the mica flakes. The direction of the flowage lines could always be fixed in the areas hitherto studied by the author without using the petro-fabric analysis of slides after the method of Bruno Sander. The mapping of flowage structures could, therefore, be performed over larger areas in a comparatively short time. In order to obtain the direction of the movement slides were, of course, necessary.

Some examples from studied areas will be mentioned. Part of the Rana ore district in Northern Norway (see Fig. 1), studied in 1939 with more recent additions (Vogt, 1945a and b), represents an area largely with styloid structures, and with minor folds, the folding axes being conformable to the flowage lines. This may be due to a largely horizontal compression of the rocks, normal to the flowage lines. For example at the Bossmo mine, the styloid structures and the minor folds are eminently developed. The ore bodies are, accordingly, narrow and thick, almost stick-like. The flowage lines

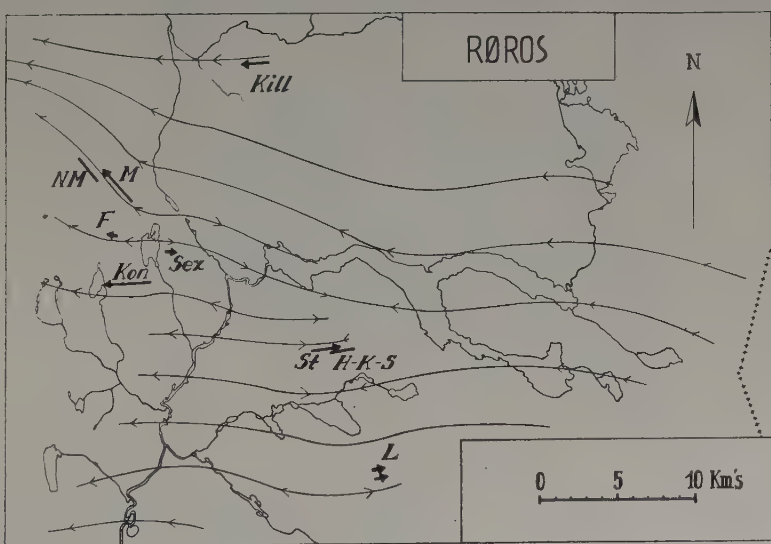

FIG. 2.—*The Røros ore district.*

Explanations as for Fig. 1. Kill = the Killingdal mine. M = the Mugg mine. NM = the Ny-Mugg deposit. F = the Fjellsjo deposit. Sex = the Sextus mine. Kon = the Kongen and Rødalen mines. St = the Storvarts mine. H – K – S = the Hestekletten, Kvintus and Solskin mines. L = the Lossius deposits.

at the Malmhaug mine were established according to drawn-out feldspar crystals in a granite sill. Styloid structures and minor folds are wanting. The ore body, accordingly, is broader and more ruler-shaped.

In the Røros ore district in Central Norway (see Fig. 2) the styloid structure and the minor folds of the type following this structure are wanting. The crystal flowage structures are rather distinct, especially to the north. At the Kongen mine an inverted fold of a special type common at the epigenetic pyrite ore deposits is conformable with the ore axis. In the Storvarts mine some folds of the same type form a rather large angle with the ore axis and the flowage structure. This feature raised, in fact, the question in the 'seventies, of the real direction of the ore body, a question now long ago cleared up through the continued mining.

At Sulitjelma in Northern Norway (see Fig. 3) the crystal flowage is very inconspicuous, at first almost invisible. The flowage structures and the axes of the pyrite ore are wholly conformable except, apparently, in one instance, viz. in the Charlotta mine. However, this discrepancy may, perhaps, be apparent only. Interesting is the bending of the axis of the Ny-Sulitjelma mine, appearing distinctly also from the flowage lines. A new deep-seated ore body was recently found through a trial shaft from the Giken mine, the shaft being placed just normal to the flowage lines.

The Foldal ore district (see Fig. 4) is especially interesting from a tectonic point of view. In the western part of the area, particularly at the Nygruven (Moltke) mine, the styloid structure is dominant, and is also accompanied by the small compressional folds belonging to this special type. The ore body, accordingly, is thick and narrowly ruler-shaped with a very conspicuous longitudinal direction. To the east, at the Gammelgruve mine and the two Gjeitryggen mines, the styloid structure and the small folds are wanting, the flowage structure being inconspicuous and represented by a very feeble crystal flowage. The dip of the foliation is very steep, almost vertical, the ore bodies apparently forming steep plates without any longitudinal direction. The flowage structures here suggest the interpretation (see Fig. 5). The thick ore bands dipping steeply to the south-west largely represent small folds independent of the ore axis, being situated almost perpendicular to the not very pronounced longitudinal direction of the ore body. In one of the mines (Nordre Gjeitryggen) new ores were, accordingly, looked for and found in the deeper parts of the mines to the north-east.

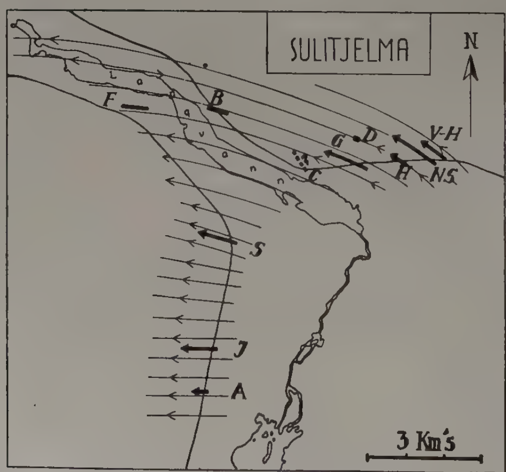

FIG. 3.—*The Sulitjelma ore district.*

Explanations as for Fig. 1. V – H = the Valdis Holmsen mines. NS = the Ny-Sulitjelma mine. H = the Hankabakken mine. D = recently discovered deepseated ore body. G = the Giken mine. C = The Charlotte mine. B = the Bursi mine. F = the Furuhaugen mine. S = the Sagmo mine. J = the Jakobsbakken mine. A = the Anna mine.

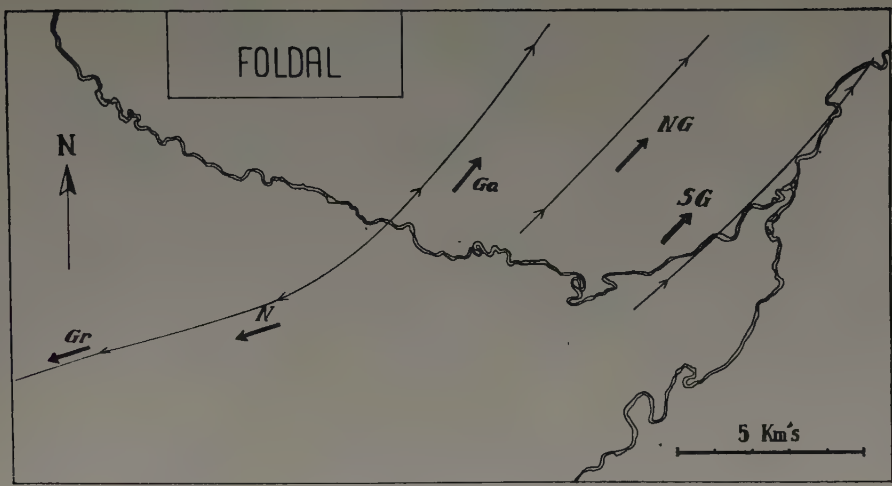

FIG. 4.—*The Foldal ore district.*

Explanations as for Fig. 1. Gr=the Grimsdalen deposit. N=the Nygruven (Moltke) mine. Ga=the Gammelgruven mine. NG=the Nordre Gjeitryggen mine. SG=the Søndre Gjeitryggen mine.

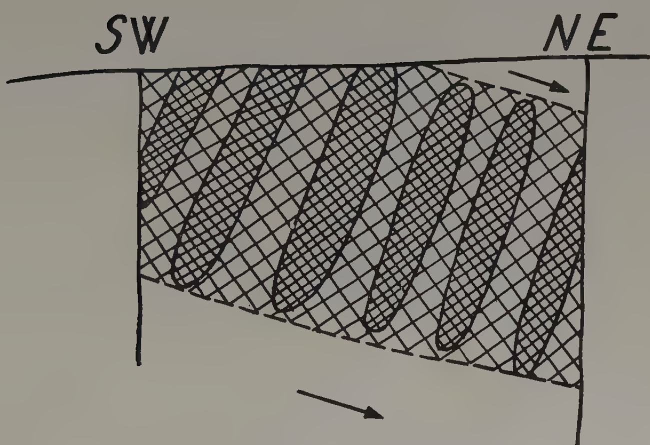

FIG. 5.—*Outline sketch of the eastern Foldal mines, representing an almost vertical plate-shaped ore body.*

Thick ore bands dipping steeply to the south-west represent the direction of folds. The arrows designate the dip of the flowage structures.

The epigenetic pyrite deposits of the types mentioned above may *a priori* have been formed before or during the period of plastic movement and deformation of the surrounding rocks. At least as regards several deposits, a formation after the deformation is hardly possible. Many of the deposits are folded and probably also metamorphosed after their formation. To a large extent, the deposits of the types mentioned above may have been formed during the plastic deformation of the surrounding rocks, and before the termination of the deformative processes.

It is a general experience from the Caledonides in Scandinavia that the stretching, or lines of flowage, are largely transverse to the general direction of the mountain chain. Reference may, *inter alia*, be made to the early papers of P. J. Holmquist (1901, 1903, 1910). The question has also been discussed by the present author (Vogt, 1927, pp. 163-169, 470-471). This experience has been corroborated by the present investigations, especially as to the more eastern parts of the Caledonides. Mention may be made of the flowage lines in the Røros district (see Fig. 2) which are representative of these eastern areas. Unpublished material points decidedly in the same direction.

The conclusion seems most natural that the flowage lines represent the lines of plastic partial movement of the rocks from the central towards the marginal parts of the mountain chain (Vogt, 1927). This may be seen in connection with the thrusts in the same direction, in the zone of rock fracture, in the most marginal parts.

As is well known, this does not coincide well with the conditions in the Alps, where the structure lines of this type according to Bruno Sander, W. Schmidt and others, are parallel and not perpendicular to the general margin of the mountain chain, and normal, rather than parallel to the movement of the rocks.

The general conceptions in regard to the formation of the present flowage structures in metamorphosed sediments are as follows. A sphere in plastic condition is exposed to hydrostatic pressure and stress, which may be resolved into three components: one normal to the plane of foliation, and two components normal to each other and lying in the plane of foliation. The sphere will then be deformed in accordance with the order of magnitude of the three components. It will be compressed in the direction of the major component, viz. the component normal to the plane of foliation, and be most elongated in the direction of the minor component. In this direction the rock will flow. If small slips do not arise, a partial movement and a rotation of mineral grains will arise. This refers to the mechanical side of the matter. On the other side, crystals growing under stress will, as is well known, attain their largest elongation in the direction of the minor component of pressure.

The discrepancy between the conditions in the Alps and in the Caledonides may, perhaps, depend upon the different depth of their rocks during the tectonic movements in question, the rocks in the Caledonides being more deep-seated than in the Alps.

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PHASES OF MOUNTAIN BUILDING AND MINERAL PROVINCES IN THE EAST INDIES*

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Netherlands

ABSTRACT

The East Indian tectonic framework west of New Guinea is formed by four, more or less concentric, orogens: (1) the presumably late Jurassic *Malaya orogen*, connecting West Borneo with East Burma through Malaya, and mainly harbouring cassiterite, gold and bauxite deposits; (2) the Cretaceous *Sumatra orogen*, running from Sumatra to Southeast Borneo through Java, with pyrometasomatic iron and Au-Ag-bearing base metal deposits in Sumatra, and iron laterites and diamond-gold placers in Borneo; (3) the Middle Miocene *Sunda orogen* (with the principal epithermal Au- Ag- and Mn-ores), running between the volcanic area of West Burma and Central Mindanao, through the inner row of Sunda islands and the west arc of Celebes; (4) the *Moluccas orogen*, shaped between late Cretaceous and middle Miocene times, running from West Burma (Arakan Yoma) to East Mindanao, through the outer row of Sunda islands including the east arc of Celebes, containing silicate-nickel and lateritic iron ores on peridotites.

Outlying epithermal Au-Ag- and Sb-Hg-ores connected with Tertiary to Quaternary volcanism occur in the western part of the Archipelago.

New Guinea continues tectonically into Halmaheira. A northern belt has lateritic iron and possibly silicate-nickel ores on pre-Neogene peridotites; Miocene Au-Cu- and Au-Ag-ores occur in the Snow Mts. and the Bird's Head.

OROGENIC BELTS IN THE EAST INDIAN ARCHIPELAGO†

FOUR main structural belts, all belonging to the Mesozoic-Tertiary alpine fold systems of the former Tethys sea, and each characterized by its own type of crustal deformation, plutonic activity and mineral deposits, constitute the geological framework of the Indonesian area west of New Guinea. Fragments of still older systems of unknown extent and obscure mutual relations are visible in isolated exposures of pre-Upper Carboniferous granites and gneisses in Sumatra, and in rather numerous outcrops of crystalline schists in various of the Sunda islands, the islands of the Moluccan area, and New Guinea. Indications of a Hercynian orogeny might perhaps be found in the general occurrence of effusives (Sumatra, Borneo, Timor, etc.) in Permian Series.

A presumably late Jurassic mountain system, for which the denomination *Malaya orogen* is proposed, emerges in the Malayan Peninsula, the islands of the Riouw-Lingga archipelago, the tin islands (Singkep, Banka, Billiton), in parts of West Borneo, in the island groups in the South China Sea, and probably also in the lowland region of eastern Sumatra, whereas some uncertainty exists with regard to the tectonic relationship of parts of the main mountain system of Sumatra. Syenitic

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* Diagrams illustrating this paper are published in " Fasen van gebergtevorming en ertsprovincies in Nederlands Oost-Indië." *De Ingenieur*, 61, *Mijnbouw en Petroleumtechniek.*

† In R. W. van Bemmelen's standard work on the geology of Indonesia (van Bemmelen, 1949), which forms an almost indispensable source of information to anyone interested in this subject, although it should be approached, in the present writer's opinion, with a very critical attitude on account of the not very fortunate circumstance that paragraphs dealing with tectonic and igneous history are intricately interwoven with their author's very personal conceptions concerning gravitational tectogenesis as the main cause of orogeny, the East Indian area is divided up into (1) older continental nuclei, (2) zones consolidated during a " Pacific " (Triassic) phase of mountain building (Malaya, tin islands, West Borneo), and (3) folds formed by "Himalayan" (Alpine) orogenesis. In the latter case, for which the main acts of crustal disturbance are assumed to have taken place between late Mesozoic and Quaternary times, the structural units of the various islands receive local denominations, correlated with the present author's structural belts in an addendum on p. 6, Vol. II of van Bemmelen's work.

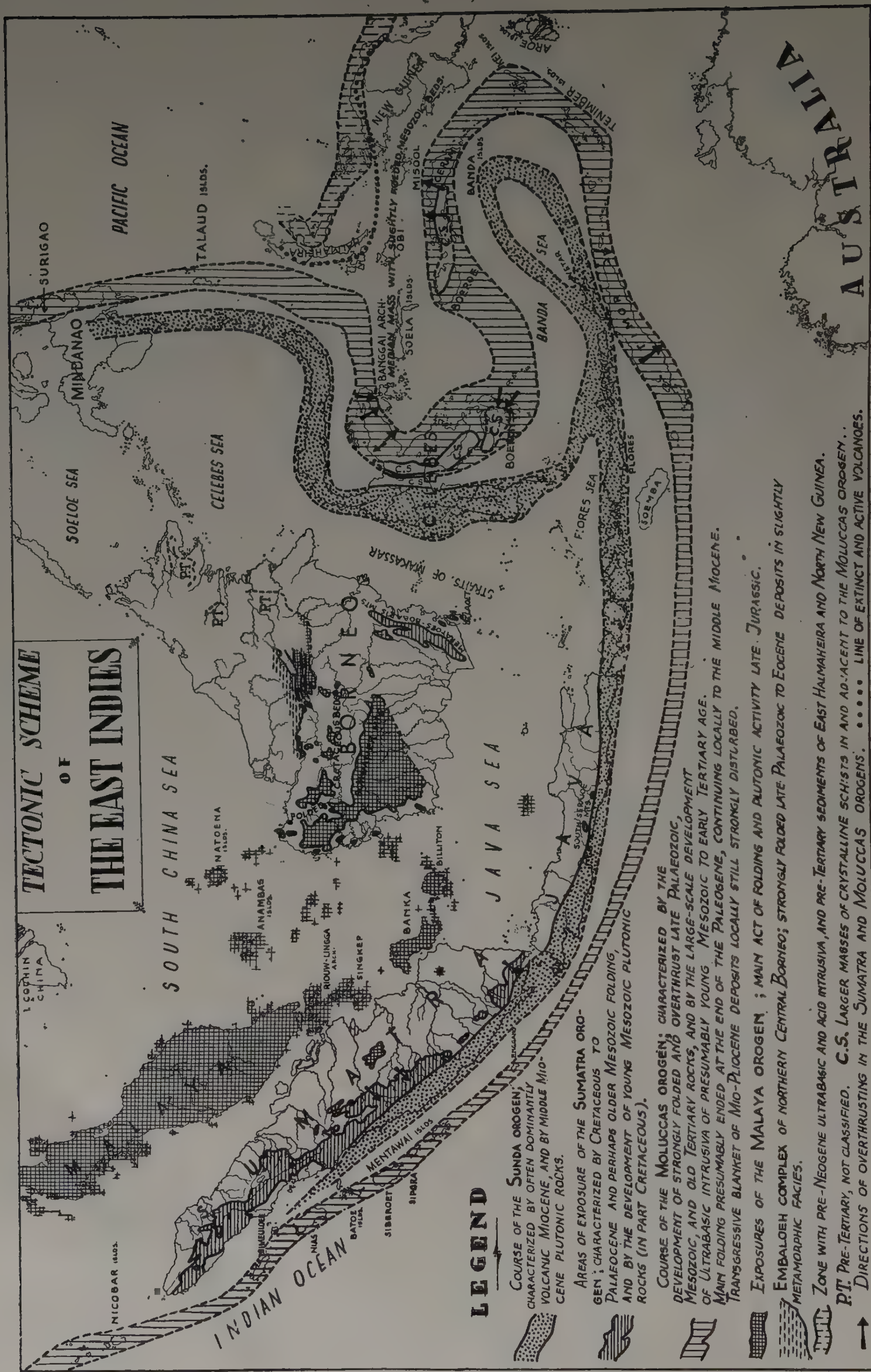

FIG. 1.—Tectonic Scheme of the East Indies.

rocks exposed in Mt. Batoe* south-east of Palembang in South Sumatra almost certainly belong to the orogenic zone of Malaya and the tin islands; a view which receives support from the occurrence of quartz-cassiterite pebbles in young-Tertiary beds near Palembang, north of the lower Moesi river. The Neogene anticlinorium on which Mt. Batoe is situated continues north-westward over the Tigapoeloeh Mts. towards the Soeligi-Lipatkain Mts., where stream tin deposits have also been exploited at a number of places. Together with the apparently complete absence of post-Triassic formations among pre-Tertiary sedimentary rocks in North Sumatra, this phenomenon points to a possibly pre-Cretaceous origin of the pre-Tertiary fold systems, or of part of them, in the northern part of this island as contrasted with South Sumatra, in which latter region strongly folded Cretaceous beds have been identified in pre-Tertiary folds of the Tembesi-Rawas and Goemai Mts. and near Lampoeng Bay.

The Malaya orogen, which connects the folds of the Sunda Shelf region through the Malayan Peninsula and South-west Siam with synchronous structures and plutonics of South-east and East Burma (Shan States), is built up largely by Permo-Carboniferous and upper Triassic sedimentary, and also volcanic, rocks, penetrated by numerous masses of granitic and tonalitic intrusives. Crystalline schists play a subordinate rôle, for instance in West Borneo, whereas there are only meagre indications concerning the development of older Triassic or Jurassic beds in this compound structural unit; only in the Sambas district in West Borneo has the existence of Liassic strata been firmly established in a limited area north of the Bawang Mts.

Plutonic rocks are developed on a large scale in the Main Range of Malaya, in the tin islands, and in West Borneo. Great batholiths of pronouncedly potassic and acid granites characterize the western part of Malaya and the tin islands, whereas more intermediate types are developed in North-east Malaya and in West Borneo, in which latter region the great batholith of the Schwaner Mts. is mainly of a tonalitic nature.

A late Cretaceous to early Eocene age of folding and plutonic activity in the Malayan tin belt and connected regions as has been proposed still rather recently by H. L. Chhibber and J. B. Scrivenor (Chhibber, 1934, pp. 294, 336, 524) has definitely been disproved by the clear establishment of the transgression of lower Cretaceous beds over both sediments and eruptives of the Malaya orogen in West Borneo. Some controversy, however, still exists with regard to the period of intrusion of the West Borneo granites, which the present writer is inclined to consider as synchronous with the unmistakeably post-Triassic acid plutonics of the tin islands. No clear unconformity has as yet been observed between upper Triassic and Permo-Carboniferous beds in Central Borneo to support the alternative view according to which they are supposed to have consolidated between the end of the Palaeozoic and the upper Trias.†

Along their south-eastern, southern, and south-western margins the folds of the Malaya orogen pass over into younger pre-Tertiary mountain belts exposed in the Meratoes-Bobaris Mts. of South-east Borneo, the South Serajoe Mts. in Central Java, and in the main range of Sumatra, whilst the northern boundary in Central Borneo is formed by an apparently gradual transition into the so-called Embaloeh complex.‡ It seems plausible to separate these younger Mesozoic structures of Sumatra, Java, and South-east Borneo as a later orogenic unit, the *Sumatra orogen*, as the writer proposed in an earlier article (Westerveld, 1941, pp. 1131-1133). Main folding acted in this zone after the lower Cretaceous; in the Sumatran mountain range and in the Javanese South Serajoe Mts. ostensibly

* The Dutch " oe " to be pronounced as the English " oo ".

† Van Bemmelen's opinion (1949, Vol. IA, pp. 725-726) that the folds of the Malaya orogen in the present author's sense were all shaped during the lower and upper Trias is definitely not backed by observations in Malaya and on the tin islands, where all granite batholiths are intrusive with regard to upper Triassic beds (Malaya, Banka), whereas for Borneo this question has not yet been settled satisfactorily, as set forth above.

‡ The folded Cretaceous beds of Central Borneo and South-west Sarawak occupy an intermediate position between the older folds of West Borneo and the younger ones of the Embaloeh complex, and might be compared orogenically with the folded Cretaceous of South-east Borneo (diamond deposits in both regions!).

between lower Cretaceous and Eocene times, and in the Meratoes-Bobaris Mts., including the region covered by the islands off the south-east coast of Borneo, apparently during the middle as well as the upper Cretaceous or Palaeocene. Plutonic activity in the latter region, however, culminated in the earlier phase with the intrusion of great masses of gabbro-peridotitic rocks.

Magmatic activity in the Sumatra orogen mainly produced gabbroic to granitic larger intrusions and consanguineous dyke rocks on Sumatra; ultra-basic facies, profusely developed in South-east Borneo, occupy a subordinate position in the western part of this structural belt. Folding generally had rather strong effects and even induced the formation of local overthrusts in Central and South Sumatra and in Central Java, which recumbent folds, however, do not seem to be comparable in size with far-reaching nappes. In Central and South Sumatra Upper Carboniferous sediments and volcanics, with older granites and gneissic to schistose rocks, were carried on top of Mesozoic beds (Djambi, Lampoeng Districts).

The Embaloeh complex of northern Central Borneo apparently differs in its structural and facial aspects from the Sumatra orogen by a development of Permo-Triassic, Cretaceous, and Eocene sediments in slightly metamorphic, phyllitic rock types, which phenomenon seems to justify its singling out as a separate orogenic unit. In a north-eastern direction this belt may probably be traced towards Mt. Kinabalu in North-east Borneo, a mass of Tertiary granite.

Cretaceous and Palaeogene folding and magmatic activity, albeit with numerous, conspicuous after-effects caused by subsequent lateral compression during late Tertiary times, affected the zone now occupied by the outer row of smaller Sunda islands west of Sumatra, by Timor and the outer Banda arc, and by the vast area of the east arc of Celebes, on a considerable scale. This *Moluccas orogen*, as it is proposed to call it, shows Permian, Mesozoic, Palaeogene, and in some sectors even older Miocene, beds involved in frequently extremely complicated structures in the eastern part of the Archipelago, where it is much more accessible to investigation than in the islands off Sumatra. Large pre-Miocene, nappe-like overthrusts were recognized on Timor by the members of H. A. Brouwer's expedition to the Lesser Sunda Islands; somewhat younger, apparently middle Miocene, phenomena of a similar kind by H. A. Brouwer, L. M. R. Rutten, and W. Hotz on Ceram (see for the elaboration of the Ceram material collected by Rutten: W. Valk, 1945, and J. H. Germeraad, 1946), and by L. von Lóczy (1933-1934) in the northern section of the east arc of Celebes.* In most cases orogenic movements were directed in a centrifugal sense, although opposite directions have also been noticed.

The transition of glaucophane-schists into Radiolaria-bearing rocks observed by W. P. de Roever (1947) in rock suites from eastern Central Celebes warrants the conclusion that part at least of the crystalline schists of the Moluccas orogen were formed through static metamorphism of Mesozoic geosynclinal deposits. Moreover, a thorough examination of metamorphic rock facies from the island Kabaena (west of the Boeton archipelago) and from Central Celebes led the same investigator (de Roever, 1949) to the conclusion that both these regions harbour large-scale overthrusts.

Intrusive rocks in the Moluccas orogen are predominantly of a gabbro-peridotitic composition and by their frequently crushed, laminated, and serpentinized character they constitute a truly pre-orogenic to synorogenic, ophiolitic assemblage. Granites are only very locally known, e.g. on Ceram, where the ultrabasic suite is besides accompanied as well by sodic, nephelite-bearing rock types. Exposures of peridotitic plutonics mark the trend of the Moluccas orogen through its entire length; from the Arakan Yoma range in western Burma through the Andaman-Nicobar islands, the islands off the west coast of Sumatra, Timor and the outer Banda arc, Ceram and Boeroe, the east arc of

* J. H. F. Umbgrove (1949, pp. 35–46), in a recent work, dates the overthrust structures of Timor as Upper Miocene (Tertiary f2), following an opinion formerly held by G. A. F. Molengraaf (1914), and not mentioning the results of the 1937 expedition to the Lesser Sunda Islands led by H. A. Brouwer. In Part VIII (Section G) of these Proceedings, however, Umbgrove emphasizes the importance of strong Laramide folding in the outer Banda arc, where succeeding Miocene phases of diastrophism are apparently thought to play a less prominent part. No explanation is however given for the change of view.

Celebes, Tofoeré, Mojaoe, and the Talaud islands to the eastern part of Mindanao in the Philippines, in which latter area they again appear in the Surigao iron ore district. The ultrabasics attain their greatest development in the east arc of Celebes, a peridotitic rock province of considerable length and presumably the most outstanding example in the world. From all available evidence, their geological age may be assumed to be late Cretaceous to early Eocene, certainly pre-Miocene. By epigenetic movements slabs of these rocks were involved in complicated tectonic structures.

Since late Mesozoic movements of a vehement nature affected the sediments and eruptives of both the Sumatra and the Moluccas orogens, the assumption seems warranted that these two orogenic belts are partly parallel and partly divergent branches of a compound Cretaceous to early Palaeogene mountain system, in which two zones with different structural and igneous features developed in almost parallel arrangement as a result of compressive forces which continued to disturb the Moluccas orogen, or outer belt, in Tertiary times. One branch of the Sumatra orogen presumably lies hidden below the Miocene volcanics and sediments of the northern row of Lesser Sunda islands, only locally emerging in Soemba, where late Mesozoic gabbros and granites are found in association with Mesozoic sediments below a weakly folded or almost horizontal sequence of Neogene strata. East-west trends in the Soemba folds and the petrology of pre-Tertiary eruptiva mark this island as a median mass rather than the tectonic prolongation of Timor, as formerly considered.

At the beginning of the Miocene, or locally perhaps earlier, the dorsal region of the combined late Mesozoic structural belt outlined above became the site of active andesitic volcanism along a comparatively narrow zone of crustal weakness approximately coincident with the area of transition between the Sumatra and Moluccas orogens. This belt turned into a longitudinal strip of zones of collapse, which were gradually filled up with a thick sequence of andesitic lavas, breccias, and agglomerates, and by Miocene sediments. At the end of the lower Miocene, this mixed series was rather strongly folded and subsequently intruded along its whole extension by dykes and bosses of andesitic and dacitic rocks, and by dioritic to granitic melts. For this newly shaped plutonic and structural belt, the denomination *Sunda orogen* has been chosen.* This remarkable zone, almost median in position between the Moluccas and Sumatra orogens, appears as a scar of impressive length, healed by Miocene volcanism, around the greater part of the Archipelago, from western Burma to the Philippines. Along its course it passes through the western coast ranges of South Sumatra, the Southern Mountains of Java, the Lesser Sunda islands, the loop-shaped inner Banda arc, the islands in the Flores Sea including Saleier, the west arc of Celebes, and finally through the Sanggi islands into the central part of Mindanao. In West Burma it is obviously represented by post-Eocene volcanics in the Mt. Popa, lower Chindwin, and Wunthu regions; in the Philippines by the belt of Tertiary volcanic rocks known for its epithermal gold-silver veins.

Post-orogenic movements, as H. Stille (1943) would call them, threw the beds deposited over extensive, previously consolidated, areas of the Archipelago after the great Oligo-Miocene transgression into folds of a mostly moderate steepness, folds which in Java, for instance, even include Pleistocene deposits with remains of hominids†. Important vertical displacements were also generated by continuing side-ward compressions, eventually resulting in conspicuous modifications of the topographical relief of the tectonic framework of the Indonesia area, which underwent no further fundamental alteration after the Middle Miocene. Island arcs and deep ocean basins, together with longitudinal fault-trough

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* The age of the Sunda orogen intrusives, which the writer formerly supposed to be late Miocene (1941, p. 1131), has probably to be put backward to the middle Miocene on account of the development of slightly tilted late Miocene volcanics, marls, and limestones in unconformable position above much more strongly disturbed volcanic formations and intrusives of the Sunda orogen in the Southern Mountains of Java.

† The comparatively young age of the folds in the Neogene oil-bearing series of Sumatra, Java, and Borneo apparently induced H. M. Schuppli (1946) to date the most important act of folding on Sumatra, Java, the Lesser Sunda islands, and in West Celebes as post-Pliocene; a conception which entirely overlooks much stronger compressions in late Mesozoic times and during the Miocene, outside the oil regions.

systems, principally owe their present existence to upheavals and subsidences; not to folding of an initial kind in Quaternary geosynclines as has frequently been suggested as part of the theory which tried to explain the Banda Sea as an area of mountain building in an embryonic stage (E. Argand, 1916; H. A. Brouwer, 1925, pp. 65-68, 1940-42, Vol. IV, p. 386). Stille's remark (loc. cit.) that the mountain systems of the Malayan archipelago are past their orogenic stage and only simulate in certain regions rows of young folds rising out of deep sea basins as a consequence of the relative weakness of positive movements, which could not prevent the partial flooding of the various orogenic belts, finds ample support in our actual knowledge of the structural development of South-east Asia.

Longitudinal fault-trough systems, which may be considered as immediately visible equivalents of submarine troughs at a much higher level, acquired their most notable development along the Sumatran mountain range and in Central Celebes. In the former case (Westerveld, 1949, Fig. 3), a rift zone follows the entire length of the island, cutting through the Sumatra as well as the Sunda orogen or coinciding with the zone of transition between these two units. Height differences up to 2000-2500 metres are measured in the northern part of this island between floors of tectonic valleys and tops of adjacent non-volcanic mountain ranges. Formidable outbursts of acid pumice tuffs, which sometimes gave rise to the formation of ignimbrite deposits (Lake Toba and Pasoemah regions on Sumatra; West and North Celebes), characterize the early Quaternary history of these graben zones, which were later fringed by eruption centres of andesitic volcanism.

Mobilization of magma reservoirs under the eastern border zone of the Malaya orogen through tectonic unrest caused by after-phases of orogeny gives an explanation of volcanic phenomena, i.e. outpourings of basaltic to dacitic lavas and tuffs and intrusions of small bodies of gabbroic to dioritic, and basaltic to rhyolitic, rocks during Tertiary and later times in Central Borneo and adjacent parts of Sarawak.

Our geological knowledge of Netherlands New Guinea, Halmaheira and interjacent island groups, albeit still rather vague, already permits the clear distinction of an immediate connection between the Bird's Head of New Guinea and the structural belts constituting the two concentric arcs of Halmaheira. A first structural and lithological unit is characterized by masses of crystalline schists covered by Neogene beds which are thrown into northward imbricated structures of a pronounced kind. Included in this unit also are slabs and wedges of Jurassic, Cretaceous (?), and Eocene strata and numerous intrusions of pre-Neogene granitic and gabbro-peridotitic rocks. This zone runs north of the Rouffaer and Idenburg rivers in Central New Guinea, whence it continues westward over Japen, the Bird's Head, Waigeo, and Salawati to the east arc of Halmaheira, in which latter region gabbro-peridotitic rocks are known to be associated with Mesozoic and Tertiary deposits. A second continuous belt is exhibited by the distribution of Quaternary extinct and active volcanoes alongside the west arc of Halmaheira, in the northern part of the north-west peninsula of this island, furthermore on Batjan, Dowora, the Five Islands, the Salo islands, Kéké, Lawien, Pisang, Kofiau, Salawati, and finally in the northern part of the Bird's Head (Arfak Mts.); a row which presumably almost coincides with a zone of Tertiary volcanism already identified in the Tamrau Mts. on the north-western peninsula of New Guinea. The first-mentioned zone bears some likeness to the Moluccas orogen, whereas the second may be a counterpart of the Sunda orogen. Their mutual age relations, e.g. with regard to igneous phenomena and main paroxysms, are possibly approximately the same.

South of the Van Rees–Gauttier–Foja–Karamoor–Bewani Mts. in northern Central New Guinea the effect of post-orogenic phases of sideward compression on Neogene beds seems to have been much weaker than north of this range to the south-west of the Cyclope Mts. near the north coast. The very insufficiently investigated broad mountain system between the Rouffaer-Idenburg depression and the Snow Mountains may presumably be largely of Mesozoic age, whereas the Snow Mts. themselves are definitely late Tertiary on account of the existence of strongly folded old as well as young Tertiary strata on the Wilhelmina and Carsztens tops and of the development of Miocene granodiorites and allied rocks (Westerveld, 1949, Fig. 6).

The Snow Mts. arose out of a geosyncline with almost continuous sedimentation at least since the Silurian: with the exception of Triassic and Cretaceous strata, which still have not been identified, the whole stratigraphical sequence from the Silurian onward has been detected. The gradual waning of the buffer effect exerted by the Australian continent probably explains the rather sudden lowering of the general height of this lofty range west of the junction with the " neck " leading to the Bird's Head, in which region Miocene folding possibly also began to loose much of its vigour. Although an immediate prolongation of the Snow Mts. into the " neck " seems a plausible solution of their connection with the Bird's Head, this relation is as yet by no means certain with the data at hand (northward overthrusting in the Bird's Head as contrasted with southward movements in the Snow Mts.!).

The curious row of longitudinal depressions on the north side of the Snow Mts., e.g. those occupied by the Wissel Lakes and followed by the Araboe and Baliem rivers (the latter north-east of the Wilhelmina top), probably indicates the existence of zones of tectonic subsidence on the boundary zone of two main orogenic units, i.e. the Miocene Snow Mts. and older structures south of the Rouffaer-Idenburg rivers.

ORE DEPOSITS OF THE MALAYA OROGEN

(Westerveld, 1949. Figs. 2,7,8,9)

The granite batholiths of the tin islands and W. Borneo mainly produced cassiterite and gold as primary minerals of economic value. These are almost entirely won from residual and alluvial deposits. Residual bauxite caps, profusely distributed over the islands belonging to the tin belt, probably also have some relation to contact zones around plutonic bodies.

Tin deposits, described elsewhere at length by the present writer, show their most important development along a narrow zone extending south-eastward from the Main Range of the Malayan Peninsula to Banka and Billiton, through the islands Karimoen, Koendoer and Singkep. This region contributed about 1,572,800 tons of tin metal to world consumption, from the island area alone, since production started on Banka in 1717, after which year this island maintained its leading position up to the present day reaching a total yield of about 1,069,500 tons of tin at the end of 1940.

Primary cassiterite occurrences include stanniferous greisen zones and cassiterite-wolframite-quartz-pegmatites in granite, the latter especially in north-west Billiton, where they are surrounded by sulphide-bearing greisen zones; also tourmaline-cassiterite veinlets in granites and Triassic sediments, which may acquire the character of stockworks; and finally larger tin veins with high-temperature as well as many sulphidic minerals exclusively known on Billiton. The Billiton veins, which are entirely developed in sediments as contrasted with the Cornwall lodes, contain a rare mineral combination of pneumatolytic silicates and oxides (ilvaite, fayalite, amphibole, biotite, chlorite, garnet, tourmaline, white mica, zircon, phenakite, topaz, cassiterite, magnetite, rarely wolframite, and probably also haematite, beryl and orthoclase) with hydrothermal sulphides (pyrite, pyrrhotite, arsenopyrite, chalcopyrite, sphalerite, native bismuth, bismuthite, galena, pyrargyrite, siderite). Magnetite and pyrrhotite are probably most prominent among the gangue minerals together with chlorite. Magnetite blocks are also reported from a few localities on Banka, and magnetite and haematite bodies from some of the Riouw islands (Lingga, Karang).

A zonal arrangement of mineralization reveals itself by the almost complete restriction of hydrothermal associations (sulphides in vein deposits, pyritization of contact zones around granites, scattered finds of native gold and manganese oxides in sediments) to the sedimentary environment of the granite areas, whereas pneumatolytic parageneses also spread over the parent rocks.

The ubiquitous occurrence of residual tin deposits over almost the whole of the more deeply denuded granite country, on Banka for instance, can hardly be explained otherwise than by the development of cassiterite as a primary constituent of the highly porphyritic and potassic tin granites together with other accessory minerals such as monazite, fluorspar, tourmaline, allanite, apatite, and

zircon. Monazite accompanies cassiterite apparently regularly in placers and might become an important by-product.

Bauxite deposits, only exploited on Bintan near Singapore (production 275,221 tons in 1940), are of the aluminous laterite type and, as far as economically important beds are concerned, apparently tied up to contact-metamorphic slates according to R. W. Van Bemmelen. A tentative explanation of this phenomenon, which is also known from Banka, where ferruginous-aluminous concretions are everywhere conspicuous around granite borders, might be found in the leaching effect of sulphuric acid solutions generated by oxidation of pyrite impregnations which are abundantly developed in Triassic shales near the margins of the acid intrusives. Bauxitization also affected the granites (bauxite pseudomorphs after orthoclase!) without generating, however, valuable concentrations because of the admixture of too much quartz.

The rarity of cassiterite, as against a relatively more abundant development of gold, copper, molybdenite, zinc, lead, and iron ores around the great batholith of the Schwaner Mts. and the Sambas region, or Chinese Districts, in West Borneo has to be explained by the less advanced state of differentiation of the Borneo granites, which are more of a tonalitic nature and often exhibit gabbroic border facies. The release of tin, a more or less lithophile element, from acid magmatic fluids requires the arrival at a high degree of acidity concurrently with the over-saturation of granite minerals with this metal; a necessity not applying to the more chalcophile minor constituents of silicate melts.

Only alluvial gold placers, found almost everywhere outside the marginal zones of the Schwaner Mts. intrusion, gained some importance in past decades. Primary gold-quartz veins have also been mined on a small scale, even up to the present day, e.g. in the Bawang Mts. north-east of Pontianak. This is a strongly mineralized region also known to contain molybdenite-quartz veins and dykes of quartz-porphyry, these apparently being good indicators of profitable gold values. Iron ores, which in one case, along the Ella river, are of a curious magnetite-apatite type associated with allanite-bearing pegmatite veinlets, reminding one of the Kiruna ores, are too scattered to be of economic importance under present circumstances.

ORE DEPOSITS OF THE SUMATRA OROGEN

(Westerveld, 1949. Fig. 3)

Primary ore deposits connected with the intermediate or acid intrusives of late Mesozoic age of the Sumatran mountain system are mainly pyrometasomatic iron and base metal occurrences, the latter sometimes with gold and silver values. The ore deposits are scattered over the whole island in pre-Carboniferous marbles (Lampoeng Districts) and Permo-Carboniferous or Mesozoic limestones (Central and North Sumatra). Besides these, a single occurrence of cassiterite-bearing pegmatite is known from the Soeligi-Lipatkain Mts., in the environment of which range tin placers have been, and until the war still were, exploited. Mention is further made of block fields of manganese oxides in the eastern pre-Tertiary ranges of Central Sumatra, of argentiferous lead-zinc veins at Soengei Pagoe east of the Moeara Laboeh valley, and of gold-bearing quartz-veins near the Goemanti river north of Moeara Laboeh. In the two last-cited cases the development of the vein systems in Mesozoic slates does not entirely preclude a much later origin, i.e. a relation with Miocene mineralization in the adjacent Sunda orogen. A relatively young age possibly also holds for cinnabar found in a couple of alluvial deposits in upper Djambi and the south-eastern Padang Highlands; those in the latter area apparently come from cavity fillings in a limestone ridge.

Practically only placer gold and a few tinstone deposits of similar mode of occurrence have thus far been proved of economic value among mineral deposits connected with pre-Tertiary Sumatran eruptives: silver-bearing lead ores of the Rawas region (north-west Palembang) in limestones and pyrometasomatic copper ores around Lake Singkarak, and possibly some pyrometasomatic magnetite lenses in the Lampoeng Districts, might become exploitable under improved conditions of transport and after more thorough exploration.

The Meratoes-Bobaris Mts. in South-east Borneo at present only derive some economic importance from placer diamond and gold deposits, which in addition carry some platinum metals. There are also a few pyrometasomatic iron ore deposits in Cretaceous limestones. The discovery of diamonds in a peridotitic breccia-pipe attests their derivation from peridotitic rocks developed in extensive masses in these ranges. Part of the alluvial diamonds seems to have reached the situations in which they are now found via upper Cretaceous and Eocene conglomerates, which are also locally excavated. The South-east Borneo diamonds may be of the same age as those of West Borneo, and of similar origin. The latter are found along the Landak, Sekajam and Kapoeas rivers also exclusively on Cretaceous and Eocene bed-rock, and likewise associated with ball-shaped pebbles of corundum-diaspore and diaspore-bearing basaltic rocks of ostensibly alien contact-metamorphic origin, but concentrated with the diamonds on account of their similar specific weight and hardness.

Thick caps of lateritic iron ores with a small nickel content cover peridotite hills near the south-east coast of Borneo (Koekoesan Mts.) and on adjacent islands (Laoet, Seboekoe). Estimated reserves are 400 million tons.

ORE DEPOSITS OF THE MOLUCCAS OROGEN

(Westerveld, 1949. Fig. 4)

First among metal deposits of this belt rank lateritic iron ores and silicate nickel ores, which have their greatest development in the east arc of Celebes, but may also both be expected outside this area on many of the Moluccas proper (Halmaheira, Obi, Fau, Roeieb, Waigeo, Manoerau), where iron ores are already known. Nickel ores of the New Caledonian type found near Malili, Lake Matano and Kolaka in East Celebes will probably gain future importance with the elaboration of suitable wet treatment methods combined with previous reduction of the ore to finely divided metal. Richest ore pockets are as a rule developed on the highest parts of hill slopes near top flats. Cobalt, manganese, chromium and iron are concentrated in lateritic caps above the Ni-silicate crusts. Reserves of lateritic iron ore found in approximately the same regions are estimated at about 500 to 600 million tons (Larona and other fields).

Attention should also be drawn to possible chromite and magnesite occurrences still insufficiently investigated. Copper ores were proved to be of secondary importance on Timor.

ORE DEPOSITS OF THE SUNDA OROGEN

(Westerveld, 1949. Figs. 3, 5, 10)

This zone of Miocene volcanism and plutonic activity mainly derives its importance as a metal region from the widespread occurrence of epithermal gold-silver veins, especially in the western coast ranges of South Sumatra, the Southern Mountains of Java, and the west arc of Celebes. Other mineralized sections of this belt, e.g. South Lombok and Flores, are not known to contain deposits of any value. There are also manganese ores and a few copper and zinc veins on Java, and scattered bodies of pyrometasomatic iron ores in Tertiary limestones on Flores and in South-west Celebes.

The Lebong region in Benkoelen and the not very far distant Salida mining district have produced most of the East Indian gold and silver output since the beginning of operations under European supervision about the year 1900. Seven mining camps yielded about 93,600 kgs. of gold and 1,006,300 kgs. of silver between 1900 and 1941 against a total production of about 112,200 kgs. of gold and 1,234,700 kgs. of silver for the whole East Indian area in the same period. Most of the vein deposits are connected with diagonal faults; only the famous Redjang Lebong mine is an exception, being related to a longitudinal fault belonging to the great median rift zone of Sumatra, the continuous activity of which caused slabs of the ore body to be faulted downwards to unexpected depths.

On Java gold-silver mining started a few years before the war in the South Bantam and Priangan districts, whereas North Celebes almost stopped working. In the latter region an occurrence in Miocene limestone (Totok) has been exploited, besides more regular types in andesitic breccias and diorite-porphyrites (Soemalata, Paleleh) and numerous stream gold deposits, the latter very conspicuously

arranged around granite masses of undoubtedly young Tertiary age. Swarms of epithermal Pb-Au-Ag veins were also found in the southern peninsula of the west arc of Celebes, the so-called Sasak region, which may be a future prospect.

In the Lebong mining district and on Java silver percentages of the epithermal ores in most cases greatly exceed gold contents, whereas North Celebes mostly produced gold in excess of silver. Many of the Lebong mines (Simau, Redjang Lebong, Lebong Soelit) were notable for their selenium content, whereas Salida also had tellurides.

The Javanese manganese mines produced $\pm$11,500 tons in 1940 from ore beds at the junction of upper Miocene limestones and underlying old Miocene volcanic breccias of the Southern Mts. The manganese ores were therefore introduced at a somewhat later epoch than the Javanese gold-silver ores, which are restricted to the lower formation. Some manganese ore is also developed in veins in brecciated and partially silicified limestone, and in Miocene volcanics.

OUTLYING DISTRICTS OF EPITHERMAL VEIN DEPOSITS

(Westerveld, 1949. Figs. 2, 3)

Gold and silver values were sometimes found in quartz veins in presumably early Quaternary dacitic to rhyolitic necks developed along the longitudinal fault-trough system of Sumatra and parallel fissures (Lampoeng Districts, Kerintji valley, Soempoer valley, Angkola Gadis valley). None of these, however, have been proved of economic value. In connection presumably with the mineralization of the Mt. Marisi rhyolite plug at the south-east end of the Angkola-Gadis valley, gold values were added to copper-bearing, pyrometasomatically altered limestones near Moeara Sipongi along an E.-W. fissure system on which mining operations started a few years before the war.

Of greater importance are the strongly manganiferous silver veins at Mangani east of the Bondjol rhyolites. The Mangani veins are found in an andesitic breccia pipe and adjacent old Neogene sediments, and are somewhat older than the Bondjol eruptives, possibly Pliocene.

Besides the above-mentioned occurrences, mineralized effusive rocks with gold-bearing veins of the epithermal type are known on the same island in the Rawas region and in the western Lampoeng Districts, in the latter case in connection with pre-Neogene lavas. The geological position of the mineralized Rawas river andesites, dacites and rhyolites is not exactly known. An approximately similar situation in relation to the main Sumatran mountain system is also occupied by pyrite-bearing lead veins along the headwaters of the Loeboek river in Central Sumatra. They are probably connected with outbursts of young-Tertiary andesites in the same region.

On Java relatively young andesite pipes of the Parang and Sanggaboewana Mts. near Poerwakarta in the western part of the island carry silver-bearing galena-sphalerite-cinnabar veins and are definitely later than the epithermal veins of the Southern Mts.

Occurrences of antimonite and cinnabar in the Sambas district of West Borneo and some of the northern gold placers of that region are probably connected with Tertiary or Quaternary volcanism which has been active in North-west, North and Central Borneo. Similar relations seem to exist in the environment of the Bojan and Tebaoeng rivers in Central Borneo, where gold is likewise associated with cinnabar and antimonite; while the intimate relation of gold-silver lodes and of cinnabar-antimonite veins to andesitic intrusions of comparable age has long been known from the abandoned mining district of Upper Sarawak (Bau, Bidi, etc.).

MINERAL PROSPECTS OF NETHERLANDS NEW GUINEA

(Westerveld, 1949. Fig. 6)

Stream gold from the Eilanden and Digoel rivers south of the Snow Mts. near the Australian border is very probably derived from epithermal precious metal veins connected with the Miocene granites which are developed in the inner parts of this high range. Epithermal vein quartz has incidentally been reported in this region and has also been found in the Tamrau Mts. in the Bird's

Head in association with propylitized andesites. Alluvial gold reported from the Bewani Mts. in North New Guinea is undoubtedly older.

Gold-bearing pyrometasomatic copper ore has been met *in situ* near a granite contact south of the Carsztens tops in the central part of the Snow Mts.

The most northern mountain ranges of Netherlands New Guinea, the Cyclope Mts. for instance, and some of the islands of the New Guinea archipelago (Waigeo, etc.) deserve attention in connection with possible occurrences of silicate-nickel, chromite, and lateritic iron ores tied up with ultrabasic intrusives.

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LAND EXPLORATION AND LAND PLANNING THROUGH GEOLOGICAL METHODS IN NEWFOUNDLAND

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ABSTRACT

A 25,000 acre area of government owned land under virgin forest was scientifically explored and planned using geological soil survey principles. The methods employed were well adapted to Newfoundland conditions where the severity of recent glaciation destroyed all of the pre-glacial soils leaving most of the land as bare rock outcrops, peat bogs, or with a covering of bouldery drift. The potential agricultural areas, which total less than one per cent of the land area of the island, have soils with shallow profile development all of which are closely related to the underlying geological materials. The techniques used in the survey were : (1) aerial reconnaissance of widespread areas, (2) geological reconnaissance on the ground after promising areas were selected through aerial observation, (3) aerial photography of areas chosen by ground reconnaissance, (4) preparation of base maps through stereoscopic studies of aerial photographs, (5) mapping of glacial deposits and topography by closely spaced geologic traverses using base maps prepared above, (6) correlation of soil types with geologic and topographic data, (7) preparation of detailed soil maps.

Land-use maps correlating topography, drainage, soil types, and soil erodibility differences were also prepared so that soil conservation practices could be applied. A polygonal or mosaic farm boundary system fitting " the natural lay or contour of the land " was used in laying out homesteads in place of the older system of rectangular or other straight line boundaries which disregarded topographic and soil variations. This scientifically planned area is being cleared of forest and developed as a homestead program for Newfoundland Veterans of World War II.

INTRODUCTION

NEWFOUNDLAND has long been a country whose economy has been based on the use of its famous fisheries and the exploitation of its limited mineral and forest resources. In recent years the government has fostered a program to expand agriculture and encourage land settlement in order to increase domestic food production and in many cases to combine subsistence farming with fishing and lumbering. Under this program the survey begun by the writer in the summer of 1941 was the first systematic approach to land exploration and land planning in the island.

GEOGRAPHIC SETTING

Newfoundland lies just off the coast of eastern Canada in the same latitude as that of France. It has a total land area of approximately 42,000 square miles which extends some 300 miles from north to south and a similar distance east and west. The population which totals a little over 300,000 lives mainly on the periphery of the island in small detached settlements where fishing is the main industry. In the interior, lumbering, mining and small-scale farming are the chief occupations.

Climatically, Newfoundland is colder than European areas in similar latitudes. The coastal temperatures seldom exceed 80 degrees in summer and sometimes drop below zero in winter. In the interior the temperatures are somewhat more extreme but even here they are favourable for the growth of many crops. The short growing season (approximately 100 frost-free days) is more or less compensated for by the long length of daylight. Precipitation is usually abundant (40 to 50 inches annually) and fairly well distributed throughout the growing season. Under these conditions crops grow luxuriantly especially the tuber crops, potatoes, turnips, carrots, beets as well as peas, beans, small fruits, hay, and other leafy crops. A considerable expansion of the agricultural industry would

materially benefit the island's economy especially hay production and an increase in the cattle industry which could be advantageously carried out with the land available.

GEOLOGIC SETTING

The surface features of Newfoundland are the result of fluvial erosion on Pre-Cambrian and Paleozoic rocks of complex structure in which the structural grain of the country trends north-east–south-west. The folded sedimentary and metamorphic strata as well as the igneous intrusive and extrusive rocks were reduced to a surface of low relief which was then uplifted to form a broad plateau sloping gently south-eastward from a crest more than 2,000 feet high along the west coast to elevations of 600 to 700 feet along the east coast. The plateau is dissected by numerous valleys the largest of which have been developed on the soft Paleozoic strata.

Glaciation in late Pleistocene (Wisconsin) time strongly affected the whole island and modified many of the surface features as well as scouring off the pre-glacial soil mantle. An aerial view of the island clearly displays the harshness with which the land was affected by the glaciers and therefore the reason for the lack of large scale agricultural development. Much of the vast area observed consists of ice-scoured bare rock and boulder-covered areas interspersed with numerous glacial lakes and peat bogs. In only a few of the drift-covered valleys and along certain fringes of the coast do potential agricultural land areas exist. Scouring was most severe on the crystalline and harder sedimentary rocks which make up the highlands whereas considerable deposition took place in the soft rock valleys. In many places where the direction of the ice movement was parallel to the general structural trend, the glacial deposits show a marked similarity to the underlying bedrock. This is particularly true where ice movements were localized and the till deposited almost *in situ*. Along the coastal fringes of the island the glacial materials were sorted and deposited in marine waters and later uplifted due to isostatic adjustment when the ice-cap melted. The amount of uplift is clearly shown by the raised beaches

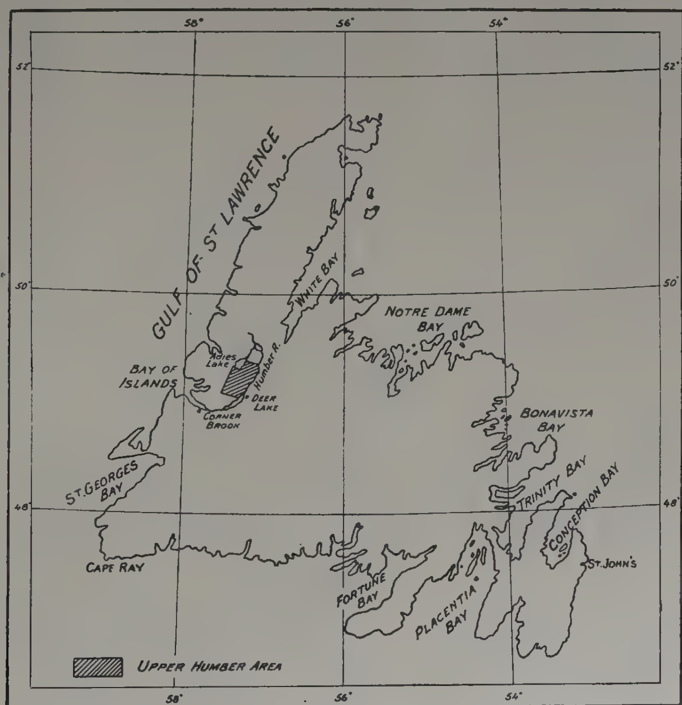


FIG. 1.—*Index map of Newfoundland.*

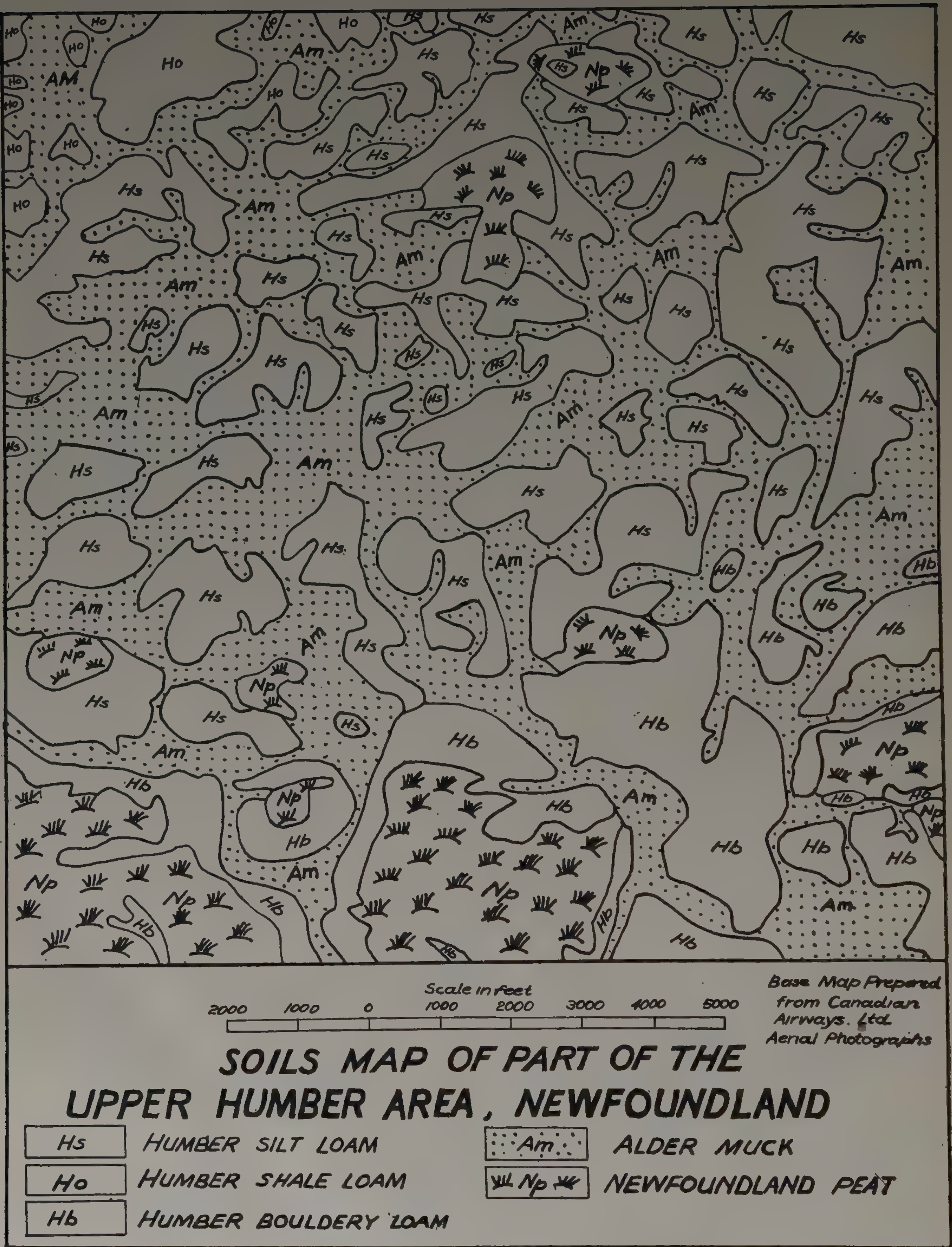

Scale in feet
2000 1000 0 1000 2000 3000 4000 5000
Base Map Prepared from Canadian Airways. Ltd. Aerial Photographs
SOILS MAP OF PART OF THE UPPER HUMBER AREA, NEWFOUNDLAND
Hs HUMBER SILT LOAM
Ho HUMBER SHALE LOAM
Hb HUMBER BOULDERY LOAM
Am ALDER MUCK
Np NEWFOUNDLAND PEAT

FIG. 2.

containing marine fossils and by wave-cut terraces which are now in places more than 200 feet above sea level. Many of the marine deposits are sites of potential agricultural land.

SOILS

All of the soils in Newfoundland have been formed since the recession of the last ice-sheet (Wisconsin time 20,000 years) and therefore have shallow profile development. They are endodynamomorphic or youthful in nature and closely related to the underlying geological materials. A wide variety of soils has been formed corresponding to variations in geological materials. Different soils have been formed from glacial till composed dominantly of silt and shale fragments and from till composed of sandstone, limestone, gneisses and schists or other materials. Soils derived from fluvio-glacial deposits likewise differ from those derived from unsorted materials. They in general are more porous than glacial till soils and are subject to greater drought during dry periods and greater loss of fertilizing minerals by leaching during rainy periods. Because of this they are adapted to different crops.

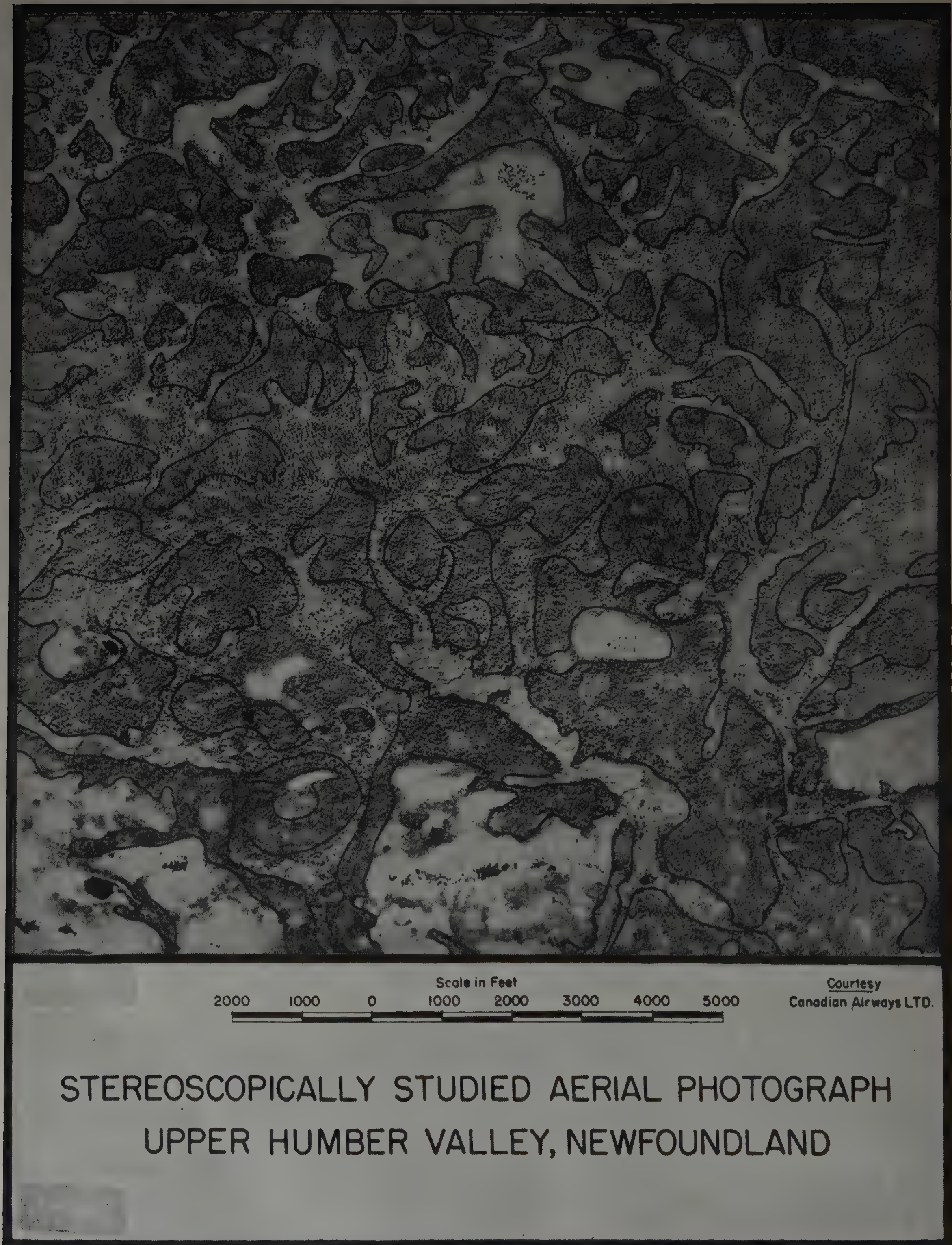
In addition to variations in geological materials, topographic and drainage conditions have also exerted a profound influence on soil development. Different soils have been formed on the same geological materials depending upon variations in topographic and drainage conditions which range from well-drained uplands to poorly drained lowlands. These variations are also influential in plant adaptability differences and crop yields. Fig. 2, shows some of the soils present in a small area in Newfoundland which are a direct expression of variations in geological materials, topography and drainage conditions.

In Newfoundland all of the soils studied belong to the great podzolic soil group. Weathering under the cool moist climatic conditions and a blanket of coniferous vegetation has produced soils with highly leached ashen gray A horizons. These soils like their podzolic equivalents in Scandinavia and in other parts of the world are deficient in nutrient minerals and therefore will require heavy fertilization for economic crop growth. In addition, due to the recency of glaciation and the short time that the weathering processes have acted on the geological materials, soil profile development even under optimum conditions is shallow (approximately 18 inches to the base of the B horizon). Because of the shallow and erosive nature of soils coupled with a rolling topography, good land-use soil conserving practices will have to be used in order to prevent losses through soil erosion and thus insure profitable farming over a long period of time.

LAND EXPLORATION AND MAPPING

In an agriculturally undeveloped country such as Newfoundland, a systematic survey of its potential land resources differs from that of other parts of the world in that most of the mapping must be done in undeveloped forest areas where there is a general obscurity of topographic features, absence of roads, field boundaries, etc. Further complications arise from the fact that most of the land is made up of bare rock outcrops, bouldery drift-covered areas, peat bogs and glacial lakes all of which are unsuitable for agricultural development. Widespread surveys carried out over a four-year period indicated that less than one per cent of the total area of the island contained land potentially suitable for agricultural development, much of which is found in small detached areas. Because many of these potential areas can be identified from the air or from aerial photographs and the fact that the soils are closely related to the geological materials, topographic and drainage conditions, a study of aerial photographs plus detailed geological and soils mapping served as a systematic approach to the land exploration program.

Studies made of aerial photographs showed a close correlation between potential and non-potential agricultural land areas and certain types of vegetation. Non-potential agricultural land consisting of poorly drained peat bogs appear as light patches on aerial photographs and the associated bodies of water are black. Severely scoured areas with bedrock exposed are almost white and show marked structural trends as well as glacial grooves and other surface markings. Potential agricultural land consisting of alder-covered muck lowlands appear as light gray areas on aerial photographs and are



STEREOSCOPICALLY STUDIED AERIAL PHOTOGRAPH
UPPER HUMBER VALLEY, NEWFOUNDLAND

FIG. 3.

characterized by the marked absence of large bodies of water. The well-drained uplands covered with fir or birch forest are dark gray and can be further identified from a stereoscopic study of aerial photographs by their higher topographic position. Aerial photographic studies of this type eliminate large areas of non-agricultural land immediately while potential areas consisting of muck lowlands and fir-covered uplands can be studied in more detail.

Promising areas selected through aerial photographic studies were surveyed on the ground using the normal geologic reconnaissance method with compass traverses spaced 1000 feet apart. The glacial deposits and correlated soil types were observed in stream bank exposures and by auger borings and the data recorded on maps. Areas which were covered with glacial drift sufficiently deep (at least several feet), were relatively boulder free and exhibited good topographic and drainage conditions as well as good soil profile development were selected for detailed surveying.

In the detailed survey a generalized topographic map was prepared through stereoscopic studies of aerial photographs. Fig. 3 shows the upland and lowland boundaries as well as drainage pattern characteristics of one of these stereoscopically studied prints. The terrain consists of a fluvially sculptured bed-rock topography covered with a thin mantle of ground moraine. This type of map enables one to record all field data with a high degree of accuracy because of the close correlation of certain soil types with topographic and drainage patterns as well as geological materials. In the actual mapping, data collected from the reconnaissance survey pertaining to the characteristics of the geological materials and soil types were used in defining the mappable units and further subdivisions were made as the work progressed. Geologic traverses were spaced 300 feet apart and auger borings made every 100 feet or closer along traverse lines. The data collected were recorded on the aerial photographs and the boundaries delineated accordingly. A detailed soil map, a portion of which is shown in Fig. 2 was prepared and incorporated in a report in which the topography, drainage, soils, land-use, and other characteristics were described in detail and general recommendations made in regard to the possibilities for agricultural development (for examples, see Wolfe, 1942, 1944).

LAND PLANNING

Because most of the potential agricultural areas in Newfoundland have a rolling topography coupled with shallow soils that are easily susceptible to erosion, the use of contour or " around the hill " farming and other soil conserving practices are essential in order to prevent rapid soil destruction. The land if improperly used could be completely destroyed in a generation of farming; it is therefore deemed essential that good land-use practices be initiated when the forest is cleared and farming operations are begun.

In order to facilitate the most advantageous application of contour farming a curved boundary system " fitting the natural lay of the land " was devised in place of the older system of dividing farms into squares, rectangles and other straight line boundaries which disregarded topographic and soil variations. Because of the difficulties encountered by the land surveyors in defining farm boundaries in terms of curves, this was later modified to a polygonal boundary system such as is shown in Fig. 4, which closely follows the natural land pattern.

Conditions were ideally suited for this type of scientific planning because the potential virgin forest areas mapped were government owned and therefore complete farm plans could be drawn before homesteads were allotted. In addition, the locations of roads, farm buildings, schools, etc., could be advantageously planned for a large region before actual development was begun. In this phase of the work the data collected in the detailed land survey was used as the ground work for the land planning and development. Land-use maps were prepared as shown in Fig. 4, from the soil maps by combining several soil types which had similar crop adaptibility properties as well as similar topographic relationships. Polygonal boundaries were then drawn on the land-use maps as shown in Fig. 4, utilizing the contour principle, allotting each homestead a combination of land-use classes which would be adapted to diversified farming. A 25,000 acre area in the Upper Humber Valley on

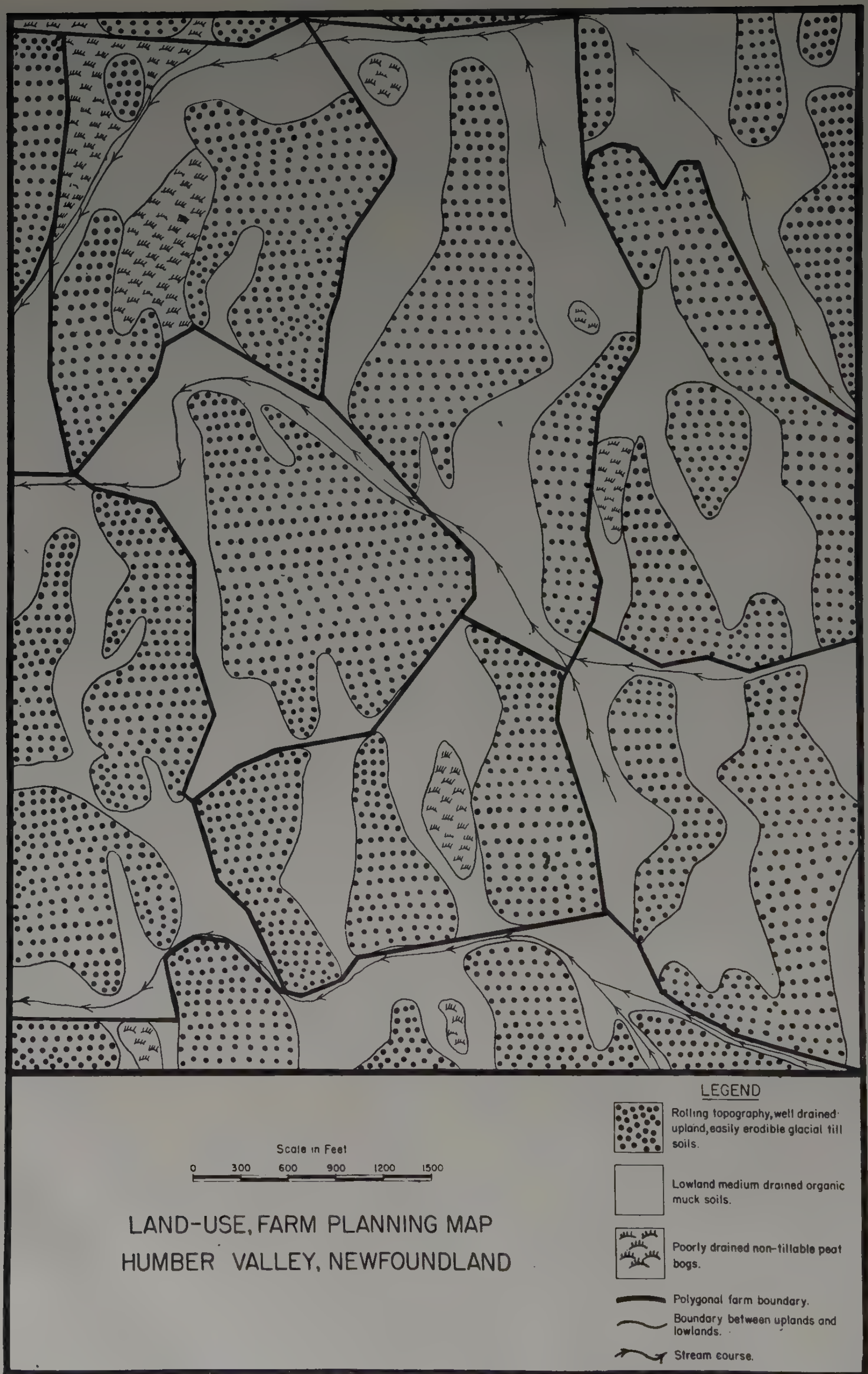

LEGEND
Rolling topography, well drained upland, easily erodible glacial till soils.
Lowland medium drained organic muck soils.
Poorly drained non-tillable peat bogs.
Polygonal farm boundary.
Boundary between uplands and lowlands.
Stream course.
Scale in Feet
0 300 600 900 1200 1500
LAND-USE, FARM PLANNING MAP
HUMBER VALLEY, NEWFOUNDLAND

Fig. 4.

the west coast of the island, scientifically planned, is being cleared of forest and developed as a homestead program for Newfoundland Veterans of World War II.

SUMMARY

1. Land exploration and soil surveying in Newfoundland differs from that of most other countries of the world in that the mapping must be carried out under forest cover where there is a marked absence of field and road boundaries and a general obscurity of topographic features. Secondly, extensive areas must be covered in order to select relatively small areas of potential agricultural land.

2. Less than one per cent of the total area of Newfoundland contains land suitable for agricultural development. This is largely a result of recent glaciation which destroyed all the pre-glacial soils leaving the island composed of ice-scoured bare rock and bouldery drift-covered areas interspersed with numerous glacial lakes and peat bogs. Only along certain fringes of the coast and in a few of the relatively boulder free drift-covered valleys do potential agricultural areas exist.

3. Weathering of the glacial deposits since the disappearance of the ice-sheet has produced soils with shallow profile development (18 inches deep under optimum conditions). All of these soils are leached and, like their podzolic equivalents in other parts of the world, will require heavy fertilization for economic crop growth. A wide variety of soil types have been formed corresponding to differences in geological materials, topographic and drainage conditions. These variations in turn express themselves in plant adaptability differences and crop yields.

4. Potential agricultural areas under forest cover were located through a study of aerial photographs and aerial observation and later mapped on the ground through reconnaissance and detailed geological and soil surveys.

5. Land-use maps correlating soil types, slopes, drainage conditions, and soil erodibility differences were prepared so that good land-use soil conserving practices could be established. This was especially important in Newfoundland because of the shallow and easily erodible nature of the soils coupled with the rolling topography.

6. A curved or polygonal farm boundary system " fitting the natural lay of the land " was used in place of the older system of dividing farms into squares, rectangles, or other straight line boundaries which disregarded topographic and soil variations. This system will greatly facilitate the most economic application of contour farming and other soil conserving practices.

7. A 25,000 acre area in the Upper Humber Valley now under forest cover has been scientifically planned and is being developed as a homestead program for Newfoundland Veterans of World War II.

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FROZEN GROUND PHENOMENA OF PLEISTOCENE AGE AND THEIR SIGNIFICANCE IN ENGINEERING PROBLEMS

By Q. ZÁRUBA
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ABSTRACT

Numerous examples of permanently frozen ground phenomena of Pleistocene age are known to exist in Central Europe. Various soil structures produced by frost action, remnants of ice-wedges and solifluction sediments of Pleistocene age have also been described from Bohemia. Most of these features occur in unconsolidated sediments of the overburden.

In Central Bohemia, frozen ground phenomena were observed also at the surface of the bedrock. This loosening and disintegration of the upper portion of the bedrock (" Congeliturbation " of K. Bryan) occurs so commonly that it has an important bearing on practical engineering problems. This is the phenomenon dealt with in the present paper.

Where the surface of the bedrock was within reach of Pleistocene frost action, the strata were disintegrated and contorted as deep as 2-4 metres. This is especially the case with shales and other thin bedded rocks. In the disturbed zone the original bedding of the rock is generally completely destroyed. The shales are broken and heaped up into minor surface folds. The individual shale fragments are lifted up and tilted so that many small cavities are formed in these shattered zones. These are either open or partly filled with clayey-loamy soil. The material of the shattered zone has the appearance of alluvial debris. If this phenomenon occurs on a slope, the disintegrated rocks are curved and dragged out, creeping downhill by solifluction.

In the surroundings of Prague, not only various Palaeozoic shales but also limestones, quartzites and Cretaceous sandstones and marls are often disturbed, due to the Pleistocene frost action.

The paper includes several examples which show clearly that when dealing with foundation on the bedrock in periglacial areas, care must be taken to determine the nature and depth of the disturbed zone.

NUMEROUS examples of permanently frozen ground phenomena of Pleistocene age are known to exist in Central Europe. Various soil structures produced by frost action, remnants of ice-wedges, fossil landslides and solifluction sediments of Pleistocene age have also been described within the territory of Bohemia. Most of these features occur in unconsolidated superficial deposits. Under favourable conditions even fossil soil profiles are preserved at certain protected localities. There they are buried under younger sediments such as loess, talus or alluvial deposits.

In Central Bohemia, frozen ground phenomena were observed also at the surface of the bedrock. This loosening and disintegration of the upper portion of the bedrock (" Congeliturbation," K. Bryan, 1946) occurs so commonly that it has an important bearing on practical engineering problems.

It is this phenomenon that will be dealt with in the present paper. For a general background a few remarks should be made concerning the climatic conditions and the evolution of morphological features of Bohemia in the Pleistocene. Bohemia was not actually glaciated in the Pleistocene, but the climate was influenced by the proximity of both the continental European glacier to the north and the Alpine glaciers to the south. In the glacial stages the climate was very cold and relatively dry, as in other periglacial areas.

Physiographically Central Bohemia may be regarded as a dissected Oligocene peneplain. The dissection occurred in the Pleistocene so that the slopes of the valleys are affected by Pleistocene weathering only. The intensity of this weathering decreases downward, towards the valley floor, inasmuch as the lower parts of the slopes were exposed to the weathering for a shorter period of time. In the uppermost parts of the valley slopes and especially on the old surface of the peneplain not only Pleistocene but even Tertiary and pre-Cretaceous weathering profiles may be found.

Where the surface of the bedrock was within reach of Pleistocene frost action the strata were disintegrated and contorted as deep as 2-4 metres. This is especially the case with shales and other thin bedded rocks. In the disturbed zone the original bedding of the rock is generally completely

destroyed. The shales are broken and heaped up into minor surface folds. The individual shale fragments are lifted up and tilted, so that many small cavities are formed in these shattered zones. These are either open or partly filled with clayey-loamy soil. The material of the shattered zone has the appearance of debris of rock weathered *in situ*. If this phenomenon occurs on a slope the disintegrated rocks are curved and dragged out, creeping downhill by solifluction.

This loosening and contorting of the surface rocks has been described also from other non-glaciated regions of Central Europe, southern England and North America. The development of opinions concerning the origin of these phenomena is of interest. The surface folding of the bedrock was explained at first only by the movement of the glacier. Thus for example H. Türach (1896) described several sections from the neighbourhood of Nürnberg and from the north of Bavaria. He interpreted the surface contortion of the weathered Keuper shales and the loosening of the Jurassic limestone as proof of the supposed glaciation of North Bavaria. M. Blankenhorn (1896) rejected this opinion and explained the origin of the surface contortion of the weathered rocks by the sliding and flowing of the thawed surface zone on the frozen ground. F. W. Sardesson studied these phenomena in the partly glaciated region of Minnesota and he distinguished cases where the surface contortion was caused either by the movement of glaciers or by freezing and thawing of the weathered surface zone. One of his examples taken from a limestone quarry near Minneapolis and described by him in 1906 (Sardesson, 1906) is quite similar to the section through the limestone surface of East Westphalia described by H. Krüger in 1932 (Krüger, 1932).

The loosening and contorting of surface beds in a non-glaciated region is now taken as proof of the periglacial climate. It is explained by repeated freezing and thawing of the surface rocks especially in the proximity of springs or zones where ground water comes close to the surface. As the freezing

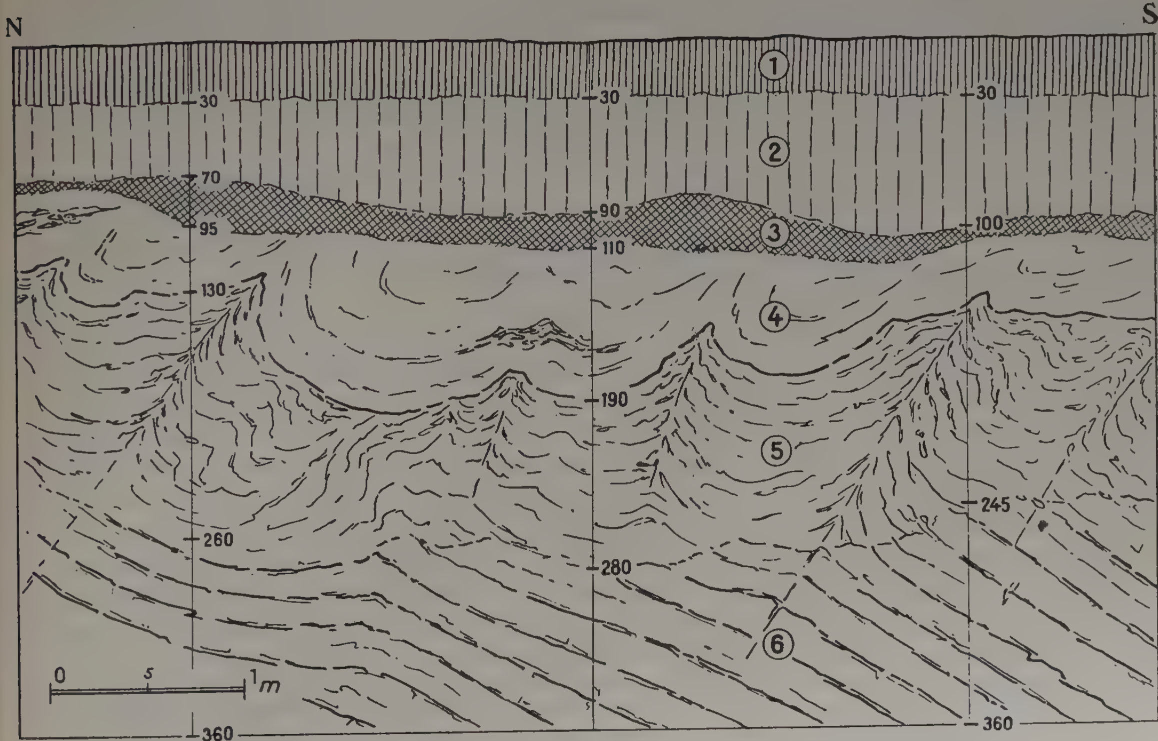

FIG. 1.—*Contortion of Algonkian shales at the surface of the bedrock.*

1: recent blackearth soil-profile; 2: loess; 3: fossil soil-profile; 4: lower loess-loam; 5: shattered zone of bedrock; 6: unweathered Algonkian shales.

penetrates the thin bedded surface rocks, thin layers of ice are formed at progressively lower horizons. Water for these ice layers is supplied from lower, still unfrozen zones, by capillary action. The process is similar to the one originally described by S. Taber (1930) as occurring in clays. During the frost period the expansion due to the formation of the ice layers causes the irregular heaving and contorting of this surface zone.

After the thawing a partial settlement of the surface occurs, but some of the shale fragments do not get back into their original position. Many of them remain tilted in a manner giving rise to numerous small cavities. In summer these cavities are filled with water which during the winter freezes and forms an ice-breccia with the rock fragments, analogous to what S. R. Capps (1910) described on a larger scale as rock glaciers in Alaska.

In the surroundings of Prague, not only various Palaeozoic shales but also limestones, quartzites and Cretaceous sandstones and sandy marls are often disturbed, due to Pleistocene frost action.* The surface contortions are often well visible on the walls of old quarries and in the excavation pits for various building purposes.

Fig. 1 shows an interesting contortion at the surface of the bedrock in a foundation pit in the north-east part of Prague. The bottom of this pit was excavated in firm shales of Algonkian age. The shales are thin-bedded, dipping at an angle of 30-40 degrees to the north-north-west. In the surface zone at the depth of 1·3-2·6 metres the beds are disturbed and the rock has the character of a loose shale debris. Some of the shale fragments occur in an erected position sub-parallel to cracks which follow the axial planes of small surface folds or plications inclined to the north. The shattered zone has not moved horizontally because some of the characteristic beds obviously continue from the unweathered zone into a weathered one. The transition from the unweathered zone into a weathered one is sudden. The boundary line appears to indicate the depth of summer thawing inasmuch as such a considerable disturbance of the firm rock could be caused only by repeated freezing and thawing of the regelation zone (" Mollisol " of K. Bryan).

The Pleistocene age of this phenomenon is corroborated by the presence of two covers of loess-loam, the lower one of which is folded or plicated along the same axial planes as the shattered zones of the bedrock. The upper loess is an undisturbed windborn deposit with a recent soil profile on the surface. A remnant of a fossil soil profile also occurs at the top of the lower disturbed loess.

The bearing capacity of the surface zone of the bedrock disturbed by frost action (" congeliturbation " of K. Bryan) is very low as was ascertained on various building sites in the surroundings of Prague. In bearing value tests it was found that the compressibility of the sands, gravels and debris was lower than that of the disturbed rock surface.

Fig. 2 gives the results of loading tests from one building site in the western part of Prague.† The compressibility of the Ordovician shales was investigated at different depths under the surface. The highest compressibility is shown by the disturbed surface layers of these shales (curves No. 1, 2 and 3) which under a load 2-4 kg/cm² showed a settlement of 5 mm. The lowest compressibility was ascertained in the firm unweathered shales (curves 5 and 6) at a depth of 2 metres under the rock surface. Settled shale-debris in which the angular shale fragments are embedded in sandy loam show less compressibility than the disturbed weathered shales (curve 4).

The loosening of the surface layers of the shales was particularly manifest in the investigations of their total, permanent and elastic compressibility. These tests were carried out in the following way:

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* We have in Central Bohemia also other typical periglacial features, fossil landslides and phenomena quite similar to cambering and bulging (Hollingworth, 1944, 1946) in our Cretaceous formation, where solid sandstones are lying on soft marls. I think that such a slope movement as cambering belongs also to the periglacial phenomena (as is tentatively mentioned by Hollingworth, 1944, p. 3, footnote), because only during the thawing of previously permanently frozen ground can we explain the necessary softening of the underlying clays or marls.

† For the bearing value test a round plate of 1000 sq. cm. was used. The testing method was described in Report No. 11 of the Institute for Research and Testing of Material and Structures of the Czech Technical University in Prague, 1932.

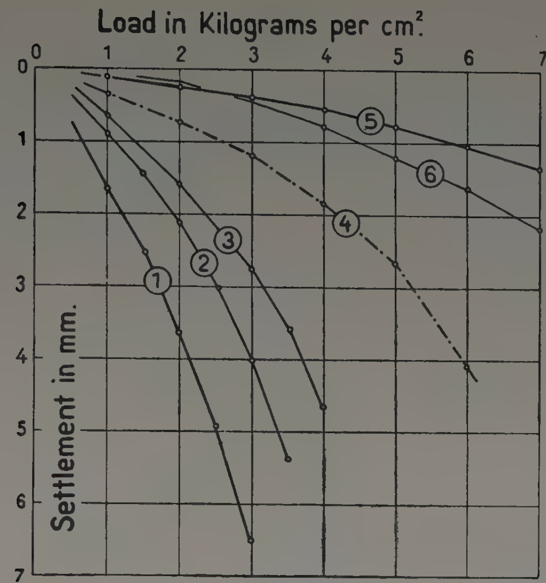

FIG. 2.—*Results of loading test of Ordovician shales.*

1, 2, 3: bearing value curves of shattered surface zone; 4: shale-debris; 5: unweathered firm shales.

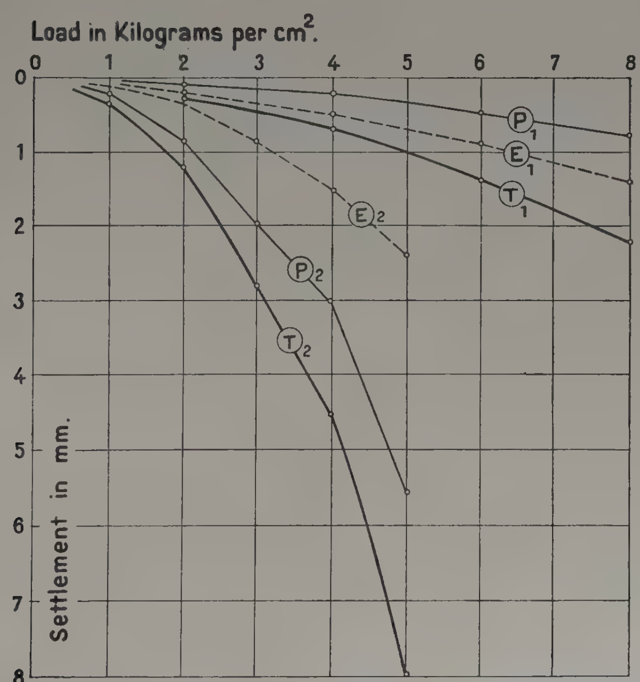

FIG. 3.—*Results of tests of total, permanent and elastic compressibility.*

E_2: elastic; P_2: permanent; T_2: total settlement of shales of disturbed zone; E_1: elastic; P_1: permanent; T_1: total settlement of unweathered Ordovician shales.

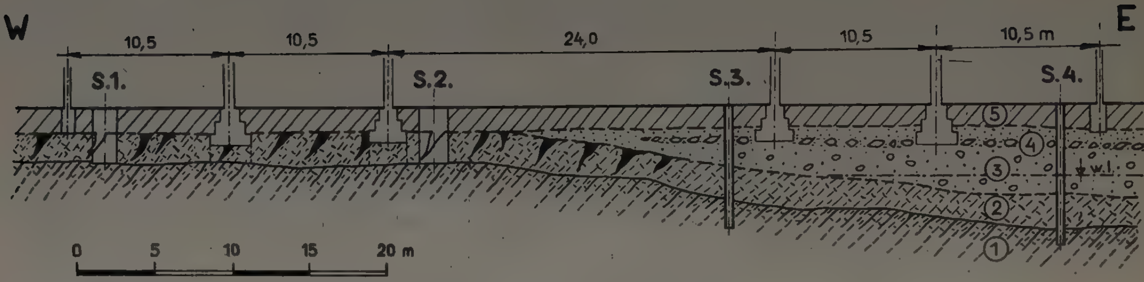

FIG. 4.—*Surface of the bedrock disturbed by periglacial frost cracks (Pleistocene ice-wedges) yields the foundation ground of a low bearing capacity.*

1: unweathered Ordovician shales; 2: disturbed zone with frost cracks; 3: sandy gravels; 4: layer of wind-worn pebbles; 5: fill-in.

after each graduation the test load was lifted and the extents of the permanent, elastic and total settlement were registered. Fig. 3 shows the results of these tests on disturbed and firm Ordovician shales at one building site in Prague XII. The disturbed shales show little elasticity and high permanent compressibility and therefore also the total settlement is very high, showing 8 mm. for a load of 5 kg/cm². On the other hand, the firm unweathered shales show a higher elastic settlement than the permanent one. Also the total settlement is only 1 mm. for the same load.

One of many examples showing the consequences of the periglacial weathering for foundations of building is illustrated by a cross-section through an excavation pit for a factory in Prague (see Fig. 4).

In this pit sandy gravels of a Pleistocene terrace were found. In the northern part of this building site a slope of Ordovician shales was exposed. On the surface the shales were weathered and loosened as deep as 2-3 metres, so that they have a character of shale debris. In this weathered zone the strata were bent and dragged down slope and disturbed by several deep cracks. On the surface the cracks have a width of 0·6-1 metre and at a depth of 3 metres they disappear. The cracks are filled with fine sand, which was probably blown there from the adjacent gravel terrace.

These cracks are obviously ice-wedges of the Pleistocene glacial period. The cracks originated as joints which were widened by the freezing of water that penetrated into them during the summer thawing in the manner that Leffingwell (1925) described from Alaska. According to the original project the building should have been founded partly on the sandy gravels and partly on the weathered shales. The unweathered shales have a very small compressibility (at the load of 4 kg/cm² the settlement only 0·35 mm.) whereas the weathered shales with frost cracks show according to the bearing value tests a very high settlement (4·49 mm. at the same load of 4 kg/cm²). Sandy gravels show also a smaller settlement (1·94 mm. at the load of 4 kg/cm²). From these numbers it is obvious that the weathered shales show at the load of 4 kg/cm² twice as high a settlement as the sandy gravels and twelve times as high a settlement as the unweathered shales. For this reason it was necessary to found the important constructions on the unweathered shales, in order to obtain a uniform settlement.

The presented examples show that when dealing with foundations on the bedrock in periglacial areas care must be taken to determine the nature and depth of the disturbed zone. When the thickness of this zone is ascertained, its bearing capacity may be determined as in the case of some other highly compressible rock. However the thickness of the disturbed zone varies greatly when compared to stratified sediments. Due to the irregular thickness and high compressibility of this disturbed zone difficulties can be avoided if the zone is removed and the foundations are placed directly on the unweathered bedrock. This is especially important in a construction requiring uniform settlement.

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DISCUSSION

A. NORVANG said that owing to the fact that the slides shown by Professor Záruba very much resembled superficial structures familiar to all Scandinavian geologists, he would like to ask a few questions. Referring to the first slide—showing " nests " of bedded material covered by loess—he would like to know whether Professor Záruba had had the opportunity of examing these structures in horizontal sections. With reference to the second slide—showing fossil ice wedges covered by the gravel of a river terrace—he would like to know whether Professor Záruba could give any information as to the age of these wedges which evidently were considerably older than the Danish ones, formed during the recession of the glacials of the last Ice Age. Lastly the speaker emphasized the importance of examining periglacial structures in horizontal section.

Q. ZÁRUBA replied that these phenomena were exposed in horizontal sections. As to the age, that was a difficulty, though they probably belonged to the last glacial period, since they were only covered by one loess and recent soil profiles.

J. B. L. HOL drew attention to the beautiful periglacial phenomena found in the Netherlands and published in the Proceedings of the Netherlands Geological Society.

TECTÓNICA DE LA REPÚBLICA MÉXICANA

Por M. ALVAREZ, Jr.
México

RESUMEN

(*Published in full in* Bull. Amer. Assoc. Petrol. Geol., 33, no. 8, pp. 1319-1335, 1949)

En este trabajo se pretende, por primera vez, dar una idea de conjunto de la tectónica de la República Méxicana, basada en los conceptos desarrollados para el estudio de los procesos orogénicos, especialmente los alpinos.

Con este objeto se dividió en dos partes: la primera, en la—que establecese el significado de los conceptos anteriormente aludidos con el fin de precisar el sentido en que serán usados e indicar en forma general los procesos orogénicos a que estuvo sujeta la República Méxicana: la segunda, en la cual se describen las grandes unidades estructurales desde el punto de vista tectónico, especialmente por lo que se refiere al carácter y orientación de los plegamientos, ya que aquél constituye el factor más importante para establecer el de las grandes unidades y separarlas.

Se han distinguido dos plataformas, dos grandes macizos y dos pequeños, así como cuatro cuencas en el antepaís del Geosinclinal Méxicano: y un gran macizo o continente, dos macizos grandes, dos medianos y cuatro pequeños, así como tres cuencas en el traspaís.

La antefosa de los plegamientos se ha señalado en tres regiones así como el carácter de " flysch " de los sedimentos depositados en—ellas.

Se considera que los plegamientos de la Cordillera se inician al oeste de Ciudad Juárez descienden hasta Torreón donde voltean hasta Monterrey y de allí al sureste hasta el Río Coatzacoalcos voltean al noroeste hasta el Río Chachijapan y al llegar a la parte más angosta del Istmo de Tehuantepec voltean al este sureste hasta penetrar en Guatemala.

Se supone que la orogenia que dió origen a estos plegamientos se inició a fines del Cretácico en el norte de la República y a principios del Eoceno en el resto de la misma terminando al finalizar el Eoceno excepto en el sureste donde se prolongó hasta principios del Oligoceno. Hubo además movimientos previos y póstumos, estos últimos muy importantes en el Istmo y Pichucalco, Tab.

INFLUENZA DEL MANGANESE SULLA METALLIZZAZIONE A GALENA. CONTRIBUTO ALLA CONOSCENZA DEI GIACIMENTI PIOMBO-ARGENTIFERI DEL PERMIANO SUPERIORE DEL TRENTINO

C. ANDREATTA
Italy

RIASSUNTO

Sono studiati i giacimenti di galena argentifera nelle dolomie degli " strati a Bellerophon " del permiano superiore del Trentino (zona di Trento-Faedo e zona della Val Pescara), giacimenti che hanno dato luogo ad una intensa coltivazione nei secoli passati. Essi sono di tipo metasomatico e parzialmente di impregnazione; la metallizzazione e dovuta ad un convoglio idrotermale di bassa temperatura (sul centinaio di gradi) che circolo e rimase a lungo entro le dolomie, specialmente contro le volte delle anticlinali, per merito del tetto quasi impermeabile dato dagli " strati di Werfen " (arenarie micacee e argillose).

Le dolomie degli " strati a Bellerophon " sono notevolmente manganesifere (MnO dal O,15% al 3,02% con media di 1,22%) e si ritiene probabile che la presenza del manganese abbia avuto influenza sopra la deposizione della galena argentifera, mediante una vera azione catalittica. Non si puo escludere in maniera assoluta che il convoglio idrotermale abbia portato una parte del manganese.

LES FACIÈS DU FLYSCH

Par I. ATANASIU
Rumania

RÉSUMÉ

Durant la phase orogénique qui s'est deroulée dans le Paléogène on peut constater, dans le géosynclinal des Carpates orientales, une certaine ordonance, dans le temps et dans l'espace, de quelques faciès differents de " flysch." Cette ordonance parait être imposée par la manière dont s'acomplit le processus orogénique:

(*a*) Dans une phase initiale, durant laquelle s'est dessiné l'aire d'orogénèse, a été sédimenté un flysch initial ou d'inondation, pélitique-calcaire.

(*b*) L'avancement et le soulévement du bloc interne a déterminé la sédimentation d'un flysch interne, au caractère de molasse.

(*c*) La réaction de cet avancement, ressentie dans une région plus externe, où se formaient les cordillères, a déterminé la sédimentation d'un flysch externe; c'est le flysch typique, qui contient ordinairement aussi des éléments exotiques provenant du fondament.

(*d*) L'exondation des plis, surtout des cordillères, dans la phase finale de l'orogénèse, provoque la formation, sur les crêtes, d'un flysch final ou de couronnement, conglomératique ou brecciforme; il passe lateralement dans un faciès gréseux qui rappèle parfois la molasse.

Donc, si l'on réserve la dénomination de " flysch " pour les sédiments synorogéniques, on peut reconnaître, dans une phase de plissement, un flysch initial et un flysch final, séparés par deux faciès syncrones: une " molasse " interne et un " flysch " externe.

ROCKS CLAIMED AS CONGLOMERATE AT THE MOINIAN-LEWISIAN JUNCTION

By E. B. BAILEY and C. E. TILLEY
Great Britain

ABSTRACT

Three localities have been examined in the North-West Highlands, Scotland:—

(1) Mam an Fhuarain, Glenelg;

(2) Glen Udalain, between Balmacarra and Strome Ferry;

(3) West of Attadale, on and near the south shore of Loch Carron.

The first has already been described by C. T. Clough, and the second and third by B. N. Peach. The authors regard the conglomerates as genuine.

Examples are also given from Loch Carron and Loch Coulin, justifying Peach and others in their claim that constructive metamorphism decreases in intensity in the Moine Schists as the outcrop of the Moine Thrust is approached from the East.

DISCUSSION

G. L. Elles said that it was important to understand exactly what was meant by the term " Torridonian " which seemed to be used to include rocks of two distinct facies. The rocks of Islay termed Torridonian had also been termed " unmetamorphosed Moines." These were probably (or possibly) the Tarskavaig Moines but were laid down under conditions quite distinct from the rocks of the Loch Torridon or Stoer-Clasrossie area. The original rocks of the Moines were water laid, the Torridonian continental. This did not preclude their being of the same age, and both were post-Lewisian. It was however possible that the Torridonian might be a little later. The difference between them, as now seen, lay not only in details concerned with their mode of origin, but in the fact that the " Moines " had formed the floor of the Dalradian geosyncline, whilst the " Torridonian " belonged to the region outside the folded area.

E. B. Bailey said that many people speaking of the Torridonian meant the 8,000 ft. Applecross arkose, which the Geological Survey called Middle Torridonian. But below this was a great thickness of Lower Torridonian, of different character. It was also 8,000 ft. thick as developed in the Sleat region of Skye.

P. Wilkinson stated that Sir Edward Bailey drew farther-reaching conclusions from his evidence in his address to the Congress than in the delivery of the paper under discussion—namely that the Moine Metamorphic Assemblage was a higher metamorphosed equivalent of the Torridonian. The evidence presented by the paper (as read) did not appear, to the speaker, to be adequate. It pointed to a metamorphism decreasing towards the Moine Thrust similar to the " dislocation metamorphism " of Read, and later Coles Phillips. It did not, however, seem to contradict the supposition (Read) that the Moines had already suffered a general metamorphism of a higher degree. The speaker therefore wished to ask the authors to present their reasons for the conclusions drawn.

E. B. Bailey said that what he called in his address the tranquil and dislocation types of metamorphism were not always in time sequence, early and late. In addition one had to remember that the stage of metamorphism of the Tarskavaig Nappe of Skye was intermediate in intensity between those of the Kishorn and Moine Nappes.

P. Wilkinson said that Sir Edward Bailey had not quite answered his point. The speaker thought that two metamorphisms could be distinguished.

C. E. Tilley said that there was specially clear evidence in the Loch Carron area of decreasing metamorphism in the Moines towards the north-west, and that this was not to be confused with destructive results of dislocation metamorphism.

A. K. Wells raised two points. First, with regard to Professor Tilley's conclusions on the equivalence of the sub-Torridonian and sub-Moinian conglomerates, the petrographical similarity did not prove that they were of the same age; but that the same materials had been laid under contribution at the time of their formation, not necessarily the same time in the two cases.

Secondly, as bearing upon the possibility of the equivalence of the Torridonian and the Moinian, the speaker suggested that too much attention was being directed to the effects of the dislocation metamorphism. Away from the overthrust zone to the west, in Ross-shire, in the so-called unmoved foreland, although the Lewisian showed the effects of regional metamorphism and intrusion by a regional swarm of basic dykes, the overlying Torridonian showed no metamorphic effects whatsoever. Therefore, as there was a fundmental difference in geological history between the Torridonian and the Moinian, it was difficult to understand how they could be of the same age.

C. E. Tilley replied that it was easy to point to other stratigraphical similarities between the Torridonian and the Moines, besides those shown by their basal conglomerates. He would also remind Dr. Wells that, though the geological histories of the Lewisian of the foreland and of its counterpart in the inliers east of the Moine Thrust had been different, this did not warrant assigning the two sets of rocks to two different formations. So, too, with the Torridonian. The Torridonian of the Kishorn Nappe undoubtedly showed a metamorphic development intermediate between that of typical Torridonian and of typical Moines.

MOINIAN-TORRIDONIAN PROBLEM: SKYE TO LOCH CARRON

By E. B. BAILEY and W. Q. KENNEDY
Great Britain

ABSTRACT

Lewisian orthogneisses of the Moine Nappe in Skye contrast mineralogically with their counterparts in the foreland, as exposed for instance in Coll and Tiree. At the same time, while retaining a consistent mineralogy among themselves, the nappe-Lewisians vary significantly in texture according to their distance from the Moine Thrust. In a belt adjacent to the latter, and sometimes two miles wide at outcrop, they are relatively fine-grained, and are also flaggy or fissile. Further away they are coarser and, though they show a conspicuous banding of acid and basic, cannot be described as flaggy. The two facies are linked by transitional types, and by the frequent occurrence of post-shearing porphyroblasts of hornblende, biotite, chlorite and albite in the fissile development. It seems clear then that the characteristic nappe-metamorphism of the Lewisian (both fissile and non-fissile) is of the same general date as the movement responsible for the Moine Thrust. Sedimentary Moinian granulites differ from adjoining Lewisian only in the proportions of their minerals and in containing garnet instead of hornblende. They certainly received their present crystallization at the same time as the associated Lewisian.

CONTRIBUTIONS TO THE STUDY OF GEOLOGY OF GOA DISTRICT (PORTUGUESE INDIA)

By A. BORGES, C. T. ASSUNÇÃO and A. PINTO COELHO

Portugal

ABSTRACT

The "Fundamental Socle" of Goa District may be considered as belonging to the "Dharwar System"; the "Basement Gneisses," however, are not present.

The oldest gneisses are those interbedded with the Dharwar schists; others occur in association with the granitic group which is intrusive in the Dharwar schists.

The predominant rocks of the "Fundamental Socle" are argillaceous, ferruginous, and amphibolic schists and amphibolites; and mica- and chlorite-schists, and gneisses.

This "Socle" is invaded by veins and other igneous intrusions of acidic and basic character (granites, olivine gabbros, hyperites, dolerites, etc.). These intrusions gave rise to cornean (aphanitic) rocks, which are found in many places.

The Deccan traps occupy the north-east corner of this territory, in Satari, where they are represented by dolerites and fine grained gabbros.

In this study an optical and chemical investigation is presented, not only of the trap-rocks but also of the basic rocks of the massif and veins.

A blanket of laterite covers the formations already mentioned. Sedimentary rocks (sand and clay) occupy coastal plain areas.

THE GREAT CIRCLE STRESS PATTERN OF THE EARTH, ITS EXPRESSION IN THE SUBOCEANIC AND CONTINENTAL RELIEF AND THE RELATIONSHIP BETWEEN EPEIROGENY AND OROGENY

By N. BOUTAKOFF

Trinidad

ABSTRACT

1. The Author presents a topographic map of the world on the Mercator projection, which shews that the major bathymetric and hypsometric features of the Earth follow two systems of conjugate directions, one of which is polar and the other equatorial.

In each system, curved directions are orientated N.E.-S.W. and N.W.-S.E., forming corresponding rhomb angles of 15° to 40° with the meridians and the equator respectively, in other words angles of from 30° to 80° between themselves. Angles approximating 60° are conspicuously prevalent.

In the resulting pattern, each N.E.-S.W. direction of the polar system is closely orthogonal with the N.W.-S.E. direction of the equatorial system and vice-versa.

2. The plotting of these trends on gnomonic world charts has led the writer to the discovery that all lines in the pattern represent portions of arcs of great circles.

3. Major epeirogenic movements are now taking place along all four trends, which also closely govern the orogenic belts of the Earth. The great circle stress pattern is therefore the expression of a single cause, which underlies both types of tectonic adjustments and is closely related to the shape of the Earth.

4. The relationship of epeirogenic and orogenic movements is discussed from this standpoint.

OLD SOILS AT UNCONFORMITIES AND THEIR AGE

By E. B. BRANSON
U.S.A.

ABSTRACT

Many unconformities have consolidated residual soils above eroded surfaces and below the deposits of an advancing sea. Such deposits have been given little attention in geologic literature, and the question of the classification of a formation composed of the old soils is an open one.

One example described lies on top of a Lower Ordovician formation, and overlying the consolidated soils is a Middle Devonian limestone. The old soils are made up of fragments of practically insoluble residues from the Ordovician and of small pebbles of chert, chalcedony, and quartz grains from an undetermined source. Several other old soils are described; one of the most significant was penetrated by roots while it was a soil and contains conodonts from an older period.

Most old soils are too thin and discontinuous to make mappable units and they must be mapped with the underlying or overlying formation. It might be worth while for geologists to agree on some consistent practice.

ALGUNAS REFLEXIONES SOBRE PLIEGUES TECTONICOS

Por J. A. BROGGI
Peru

SINTESIS

Después de hacer notar la incertidumbre existente sobre la definición de pliegue tectónico, se ocupa el autor de su clasificación en singénicos y epigénicos, como del fenómeno de plegamiento y desplegamiento, el útimo de los cuales no ha sido aún tratado por los tectonistas. Analiza después los pliegues bajo su aspecto geométrico, agrupándolos en lineares, laminares y macizos, para esbozar la subdivisión en puros y mixtos, terminando por la interpretación tectónica de los pliegues lineares geométricos.

KOTSCHUBEITA DE LA SIERRA DE LA CAPELADA, CABO ORTEGAL, GALICIA (ESPAÑA)

Por G. MÁRTIN CARDOSO e I. PARGA PONDAL
Spain

RESUMEN

En el macizo montañoso que forma el Cabo Ortegal, al extremo norte de la provincia de La Coruña, existe un batolito de rocas básicas formado principalmente por piroxenitas cromíferas. En las serpentinas procedentes de la alteración de estas piroxenitas se encuentran con frecuencia cloritas, tambien cromíferas, en láminas de tamaño variable, flexuosas, de un hermoso color verde con viso violáceo, y a veces con reflejos plateados. Algunas llegan a alcanzar 200 cm². de superficie. El análisis químico de la fórmula:

$$5\,SiO_2.\ 2\,(Al, Fe, Cr)_2O_3.\ 8\,MgO.\ 12\,H_2O$$

$$\text{La relación molecular: } \frac{Si\ O_2}{R_2\ O_3} = 2{,}4 \text{ y } \frac{Cr_2\ O_3}{Al_2\ O_3} = 0{,}08$$

se aproxima mucho a la composición de la Kämmererita de Newcastle (California). Pero teniendo en cuenta que en todos los ejemplares estudiados procedentes de la Sierra de la Capelada, las muestras tie nen siempre signo positivo y $\rho < v$, debe ser considerada más bien como Kotschubeita, de acuerdo con la clasificación adoptada por J. Orcel en ses " Recherches sur la composition chimique des chlorites," Paris, 1927,

$$\text{Densidad} = 2{,}699;\ \text{birrefringencia media} = 0{,}0115.\ 2E = 22 \text{ a } 28°$$

La pequeña proporción de $Cr_2\ O_3$ explica que el color del mineral sea verde con solo ligera tonalidad violácea.

SLICES OF CRYSTALLINE ROCKS IN SEDIMENTARIES (ALPINE GEOLOGY)

By LEON W. COLLET

Switzerland

ABSTRACT

(*Published in full in* " La géologie du versant Sud du massif de Gastern." *Eclogae geologicae Helvetiae*, 40, no. 2, pp. 257-281, 1947).

Many instances of slices of crystalline rocks in sedimentary ones are met with in the High Calcareous Alps of Switzerland.

This phenomenon can be explained in three different ways:

(1) Friction exerted by a nappe on autochthonous sediments may, in some places, peel off these latter and scrape the crystalline schists or granite of the substratum as though by a gigantic plane. The resultant shavings, or slices, are then carried forward beneath the reversed limb of the sediments of the nappe on to the sedimenary cover of the granite foundation. This phenomenon has been recorded by the author.

(2) A crystalline wedge due to foundation folding may be elongated and crushed by the forward movement of overriding tectonic elements, forming slices that become detached from the main wedge. These may then be carried along intercalated in sedimentary rocks which formerly covered the crystalline rocks before the formation of the wedges.

(3) Lugeon, at the beginning of 1948, put forward the view that the crystalline slice he discovered in 1912 at La Rionde did not originate as a crystalline wedge of Mont Blanc. He considers this slice, and also the one of Salanfe, as a landslide in the Nummulitic sea. The author has found another case that might be explained in the same way.

DISCUSSION

O. HOLTEDAHL said that he would like to hear what objections there were to a tectonic origin. In the Caledonian Zone of the Scandinavian Peninsula there occurred quite commonly slices of tectonically uncovered rocks which had now no connection with the rock masses from where they had come, e.g. crushed Archaean granite in metamorphic sparagmite or Cambro-Silurian schists.

P. H. KUENEN asked whether the very varied composition indicated slumping, as a tectonic slice might be expected to be of more uniform composition. If indeed it was a slump, then its shape seemed to indicate much subsequent deformation by tectonic movement.

R. B. MCCONNELL said that when mapping an area of the Niesen Flysch in the Alps he had found blocks of Jurassic limestone, upwards of 1000 metres in size, which had slid for a distance of more than 10 kms. into upper Cretaceous sediments. These blocks were the remnants of landslides which took place on the steep talus of an advancing arc during the preliminary phase of the Alpine movements.

C. I. MIGLIORINI asked Professor Collet whether he thought that the Jurassic limestones in which the granite slices of the Inneres Falfertal were embedded had the consistency of calcareous mud when they were deposited.

E. B. BAILEY said that these phenomena occurred on various scales. Those first described by Lugeon were in the Flysch; he would be glad to know the dimensions of Lugeon's slices and those of Collet.

L. COLLET replied that the dimensions in Lugeon's case were much greater. There was a slice of granite 600 metres in length, broken into two parts. It was wrapped in breccias in which were dolomitic limestones of the Trias; quartzites of the lower Trias; and a few elements of granite. McConnell had described lenses of Jurassic in Flysch. In the Graubunden Cadisch had dealt with masses of rock that had slid in the sea. The cases which the speaker had described had puzzled him for a long time. He drew attention to the frontal part of the granite patch, where the limestone folded round the granite. There was no certainty yet, but it did seem that in the past the tectonic phenomena had been exaggerated a bit too much.

E. B. BAILEY said that the more he thought of Lugeon's scale, the more impossible he thought it was to accept those as landslips. He was not troubled by the folding of the Trias around the granite.

C. I. MIGLIORINI said that Professor Collet's very clear description of the granite slices embedded in the malm on the left bank of the Inneres Falfertal also reminded one of the Argille Scagliose exotics, so that it might be suggested that this phenomenon was brought about by similar slips, the calcareous mud of the malm having slipped, together with the granite slices embedded in it, before it had been consolidated.

A RE-INTERPRETATION OF THE GEOLOGICAL SEQUENCE IN THE GLACIER ROGERS PASS SECTION OF THE SELKIRK MOUNTAINS, BRITISH COLUMBIA

By A. H. COX
Great Britain

ABSTRACT

The apparent sequence along the C. P. Railway, through the Selkirks, was described by R. A. Daly after a reconnaissance survey in preparation for the International Geological Congress Meeting in Toronto, 1913. Daly considered that, west of the summit syncline of the Rogers Pass Divide, the strata were disposed in a steadily descending sequence westwards, from the Lower Cambrian of the divide, through Beltian to Pre-Beltian (Shuswap) formations in the west. Later H. C. Gunning, of the Canadian Geological Survey, found extensive overfolding in the western part of the supposed sequence.

The present author had the opportunity, assisted by grants from the Geological Society of London J. B. Tyrrell Fund, of spending parts of two field seasons in an examination of the Rogers Pass and Glacier area of the Selkirk divide. The construction of the Connaught Tunnel had yielded exposures which were not available to Daly. On the east side of the summit syncline it proved possible to effect a complete correlation with the succession of Pre-Cambrian and Lower Cambrian rocks of the Prairie Hills and Dogtooth Range which form the northern part of the Purcell Mountain System, in which the succession had been established by Dr. C. S. Evans of the Canadian Geological Survey. As a result it becomes necessary to reclassify the groups postulated by Daly and their supposed equivalents on either side of the summit syncline. For example, an anticlinal inlier of Pre-Cambrian rocks has been found to cross the Glacier area and, as a consequence, the Ross quartzites of the western side have been found to be an entirely different formation from their supposed equivalents on the eastern side. As a further result it is now possible to fix the position of the Cambrian base with greater accuracy, and to obtain a measure of the Lower Cambrian transgression.

THE MIDDLE CRETACEOUS FACIES OF THE SOUTH OF THE BALTIC SEA COAST AND THE ADJACENT REGIONS AND THE PRINCIPLES OF A ZONAL CORRELATION OF THESE DEPOSITS

By I. A. DALINKEVICHIUS
U.S.S.R.

ABSTRACT

We owe our previous information concerning the Middle Cretaceous deposits of the south of the Baltic Sea coast to F. Noetling (1885), B. Spylski (1910), O. Linstow (1918), J. Sameonowicz (1925).

The works of the author have revealed a considerably wider former distribution of Middle Cretaceous, particularly Albian, deposits and their subsequent denudation, caused by frequent movements of the bottom of the Middle Cretaceous sea, having variable magnitudes and directions. It is to these motions that J. Raon ascribed the nature of transgressions (for the Arnager deposits of Bornholm: in the Lower Albian, Upper Albian, Middle Cenomanian, Upper Turonian) and regressions (for the same deposits: in the Middle Albian, Lower Cenomanian, Upper Cenomanian–Lower Turonian).

The wave of transgressive and regressive movements of the Middle Cretaceous sea spread, with a certain delay, to the areas situated east of Bornholm; so that the Middle Cretaceous sea appeared in central Lithuania in the Middle Albian. In the Lower Cenomanian followed a new, distinctly pronounced transgression. Later Upper Cretaceous transgressions—the Upper Turonian and particularly the Upper Senonian—have in some places entirely destroyed the older Cretaceous deposits.

In the lower portion of the Middle Cretaceous deposits, greenish sands containing teeth of Selachii have been found.

The greenish-black and grey glauconitic sandy loams of Middle Albian age are overlain by greenish clayey coarse-grained sands and black clays with inclusions of phosphoritic sandy nodules and accumulations of glauconitic sand.

These deposits lie at the base of Lower Cenomanian rocks and may be with great probability interpreted as Upper Albian shallow-water sediments partly over-washed and re-deposited by the advancing Cenomanian sea.

The Lower Cenomanian deposits are represented by greenish-grey, glauconitic, sandy clays, passing upward to glauconitic marls. The upper portion of these deposits is conglomeratic and was formed by the advancing Upper Cretaceous sea.

ANALYSE STRATIGRAPHIQUE ET STRUCTURALE DU CRISTALLOPHYLLIEN

Par ANDRÉ DEMAY
France

RÉSUMÉ

Pour la phase principale de métamorphisme régional, de nombreuses observations mettent en évidence dans les *séries paramétamorphiques*, en dehors des zones d'influence magmatique directe, un *ordre de succession régulier*: phyllades (schistes épimétamorphiques), micaschistes, paragneiss à muscovite et biotite, paragneiss à biotite.

Au contraire les gneiss d'injection et migmatites ne présentent pas une succession constante, en raison de l'existence fréquente de *zones d'injection de forme laccolitique*.

L'*analyse structurale du Cristallophyllien* a pour objet de définir la succession complexe des phénomènes de métamorphisme ou d'injection et d'orogénèse ou déformation et surtout les phénomènes orogéniques essentiels qui ont affecté le Cristallophyllien après la phase principale de métamorphisme régional.

Elle comporte l'étude des directions axiales et des structures transversales, qui sont définies, d'une part, par *les formes géométriques*, d'autre part par la *répartition du degré métamorphique*, enfin par l'observation des *structures de détail* et de la *microtectonique*.

Deux cas particuliers importants doivent être notés, celui des parties hautes, où il est possible d'établir des *relations avec la tectonique sédimentaire normale* et celui de la *tectonique profonde*.

NOTIZIE SUI GIACIMENTI FERRIFERI DELL'ALBANIA

Por A. DESIO
Italy

RIASSUNTO

I giacimenti di ematite e di limonite dell'Albania centrale, particolarmente diffusi nei territori di Qukës e di Pogradec, sono intercalati fra la formazione serpentinosa (sottostante) ed i calcari della Creta superiore con rudiste. Alla base della serie calcarea esiste un banco di conglomerato che ha tutti i caratteri di un conglomerato di trasgressione.

Il minerale è di tipo prevalentemente limonitico, ma presenta pure spesso facies concrezionare con noduli più o meno abbondanti di ematite. Si tratta nel complesso di giacimenti di tipo eluviale, che dimostrano qua e là indizi di rimaneggiamento da parte di acque superficiali. Il Fe proviene dai minerali femici di cui è relativamente ricca la formazione serpentinosa sottostante. La posizione altimetricamente elevata del livello ferrifero rispetto ai fondi delle valli attuali e l'intenso frazionamento morfologico della regione hanno causato la scomposizione del livello mineralizzato in numerosi lembi isolati, situati presso le sommità dei rilievi montuosi.

ESTADO ACTUAL DEL CONOCIMIENTO GEOLÓGICO DE LA PATAGONIA

Por E. FERUGLIO
Argentina

RESUMEN

El conocimiento geológico de la Patagonia ha experimentado, en los últimos veinte años, un considerable progreso, mediante el esfuerzo conjunto de numerosas comisiones de estudio enviadas por el Gobierno Argentino (especialmente por Yacimientos Petrolíferos Fiscales), de algunas expediciones patrocinadas por instituciones científicas argentinas y extranjeras y de investigadores privados. El autor, que ha seguido y en parte dirigido dichos trabajos durante varios años, expone en su nota los puntos principales que han sido objeto de estudio y los problemas resueltos o todavía en discusión, como ser los relativos a la edad de las plutonitas y de los terrenos metamórficos de la Cordillera y de la Meseta; a los terrenos paleozoicos; a la edad de los complejos eruptivos " porfirítico " (Triásico superior) y " porfírico " (Jurásico medio-superior), establecida a base de la posición estratigráfica y de documentos paleontológicos; a la secuencia de los terrenos marinos y continentales liásicos, jurásicos y cretáceos; a la posición del límite entre los terrenos cretáceos y cenozoicos; a las series continentales y marinas cenozoicas, inclusa la serie eruptiva " andesítica," etc.

GEOLOGY AND STRUCTURAL ENVIRONMENT OF THE IRON-ORE DEPOSITS OF MEXICO

By T. FLORES

Mexico

ABSTRACT

(*Published in full in* Economic Geology, 1950, 45, no. 2, pp. 105-126).

The most important Mexican iron-ore deposits occur along the Pacific slope of the continent and, sporadically, in the north-eastern and central parts of the high plateau. They are found only in certain physiographic and geologic provinces and are related to great orogenic uplifts, which were accompanied by deep fracturing, faulting, complex folding and igneous intrusion.

Intrusive and extrusive igneous rocks (principally granite, granodiorite, monzonite, andesite and rhyolite) of different ages, and marine sediments mainly of Cretaceous age, are the predominating host rocks.

Genetically the deposits may be classified into four groups: (1) metasomatic replacements (mainly martite with some magnetite and hematite); (2) bodies formed along igneous contacts (magnetite and hematite); (3) magmatic segregations (magnetite); and (4) residual deposits formed as a result of the weathering of basic rocks, composed of ochre, useful as a pigment.

According to their reserves, the deposits may be placed in four groups, which, in decreasing order of magnitude, contain 15-25 million tons, 5-10 million tons, 1-4 million tons, and less than 10 thousand tons.

This paper is accompanied by general maps which show the geographic and geologic distribution of the iron-ore deposits, together with several detailed maps and a production graph.

BARRAGE DES BENI BAHDEL (ORAN): ÉTANCHEMENT DE LA FONDATION DE L'ÉVACUATEUR DE CRUES

Par M. GAUTIER

Algeria

RÉSUMÉ

Le Barrage des *Beni Bahdel*, sur l'Oued Tafna, à 28 km. au S-O de Tlemcen, comprend en réalité trois ouvrages: le barrage principal, fondé sur les grès et marnes schisteuses du *Lusitanien*; une petite digue fondée sur des marnes et grès du *Callovo-oxfordien*; une grande digue, formant évacuateur de crues dans sa partie centrale, et fondée sur les marnes franches du *Bajocien.*

Contrairement à toute attente, c'est ce dernier ouvrage qui, du point de vue de l'étanchéité de la fondation, donna les craintes les plus sérieuses. Sans qu'il soit possible de s'étendre ici, on note que cette particularité tient au double jeu d'un système compliqué de failles et de variations rapides de faciès. La recherche de la solution au problème ainsi posé donna lieu à une campagne de sondages suivie de mesures et d'essais pleins d'enseignements.

De plus, lorsque la zone des pertuis naturels provoquant les fuites fut bien connue, il fallut innover pour la traiter; le manque de ciment dû à la guerre fit utiliser, pour les injections, un mélange ternaire fait d'un peu de ciment, de marnes stéaritiques provenant de certains niveaux du *Lusitanien* et de sables de concassage des grès du même âge. La réussite fut telle que la méthode paraît devoir survivre.

INTERPRÉTATION THERMODYNAMIQUE DES PHÉNOMÈNES OROGÉNIQUES ACTUELS ET TERTIAIRES

Par L. GLANGEAUD
France

RÉSUMÉ

Pour expliquer les phénomènes orogéniques sans utiliser des mécanismes non vérifiés, l'auteur examine la répartition des énergies correspondant aux plissements. Il classe les régions du globe en plusieurs groupes:

(*a*) Une partie des orogénèses a débuté à la limite de deux masses crustales de propriétés physiques différentes (masse continentale sialique et masse sous-océanique simique, par exemple). L'auteur montre, par un raisonnement thermodynamique, que le gradient maximum d'échanges énergétiques est situé, dans un tel cas, à la limite de ces deux masses. Ce maximum se traduit par les phénomènes *liminaires* (marginaux) des continents (chaînes péri-pacifiques, asiatiques et américaines; archipels entre la Birmanie et Timor, Afrique du Nord, etc.).

(*b*) Dans un géosynclinal devenu étroit, les deux marges continentales, assez rapprochées, présentent, chacune, des phénomènes liminaires. Leurs effets se conjuguent. Le phénomène global est alors généralement plus intense (chaîne alpine entre Gibraltar et l'Inde, chaînes bordant la mer de Banda entre la masse australienne et la masse sud-asiatique).

(*c*) Appliquant ces conceptions thermodynamiques à d'autres cas, on peut expliquer la répartition des phénomènes orogéniques et éruptifs.

THE GEOMORPHOLOGY OF THE SOUTH-WEST LANCASHIRE COASTLINE

By R. K. GRESSWELL
Great Britain

ABSTRACT

The great area of blown sand, the great tidal range, and the total absence of shingle, enable the processes of a sandy shoreline to be well studied in this area. Along most of its length the foreshore shows a series of fulls and lows producing a wave-like profile of wave length about 500 ft. and amplitude 3 to 5 ft. These lie mutually parallel and parallel to the coastline at Formby, but north and south of that central point they tend to be inclined away from the coastline, attempting to lie normally to the direction of approach of the dominant waves. Rapid erosion has recently replaced accretion at Formby; there is accretion north of Formby; and there was erosion south of Formby until the longshore meandering of the mouth of the river Alt was prevented by a dam in 1936. The frequency of wind in different directions, the gale directions, the direction of maximum length of fetch and the lie of the fulls and lows, all indicate longshore drifting of beach material from Formby Point in both directions, and this provides an explanation of the apparently mutually contradictory phenomena of this coastline.

THE POST-GLACIAL HISTORY OF SOUTH-WEST LANCASHIRE

By R. K. GRESSWELL
Great Britain

ABSTRACT

The end of the Pleistocene Ice Age found the Lancashire coastline well out in the Irish Sea, probably about the Isle of Man. Erosion set in at once, and a beach and cliff, traceable in places, in boulder clay, reached as far as Halsall, over 4 miles east of the present coastline. Excessive isostatic recovery then drove the sea westwards again, producing at first a sandy beach, whose deposits, now mapped as Shirdley Hill Sand and as blown sand, are spread for some miles inland of their place of deposition; and later a muddy one, whose deposits are now known as Downholland Silt and appear on the present surface in only a very few places. Further recession enabled forests of oak and birch to flourish, and blocked drainage produced conditions favourable to the formation of peat. The peat, with the stools and roots of trees in its base, now covers almost all the Downholland Silt and much of the Shirdley Hill Sand, and forms a rich arable soil that is intensively cultivated. Isostatic settling or a eustatic rising of sea-level, or both, caused a second eastward advance of the coastline to the position it now occupies, with the deposition of considerable quantities of blown sand, now forming an extensive area of dunes and a wide foreshore.

GROUND PHOTOGRAMMETRY APPLIED TO LARGE-SCALE GEOLOGICAL MAPPING

By T. HAGEN
Switzerland

ABSTRACT

Die Publikation beschreibt in einem ersten kleinen Abschnitt das Prinzip der terrestrischen Photogrammetrie unter Anwendung von Präzisionsinstrumenten. In einem allgemeinen Abschnitt wird auf die grossen Vorteile hingewiesen, welche sich daraus ergeben, dass die geologische Kartenaufnahme nicht wie bisher auf einer topographischen Karte vorgenommen wird, sondern direkt auf Photographien. Bei der photogrammetrischen Methode wird die Feldarbeit wesentlich vereinfacht, abgekürzt und somit auch wirtschaftlicher gestaltet. Die gleichzeitige Auswertung der topographischen und geologischen Karte mit den Stereo-Autographen (plotting-machines) hat den Vorteil, dass die Geologie mit der gleichen Genauigkeit wie die Topographie erhalten wird. Ausserdem braucht die Feldaufnahme in vielen Fällen nicht das ganze Untersuchungsgebiet flächenhaft zu umfassen, sondern kann sich auf wichtige Zonen beschränken. Mit Hilfe der Photographie und des Auswertegerätes kann oft auf Grund einer Linearen Feldaufnahme eine flächenmässige Auswertung vorgenommenwerden.

Es werden zwei Beispiele erwähnt, welche mit der photogrammetrischen Methode hergestellt worden sind. Das eine betrifft eine geologische Karte 1:5000 mit rein wissenschaftlichem Wert, das andere die geologischen Arbeiten für eine Talsperre. Aus diesen Beispielen ist ersichtlich, wie mit der photogrammetrischen Methode viel genauer und rascher gearbeitet werden kann als mit den herkömmlichen Methoden.

Am Schluss werden noch einige weitere, allgemeine Anwendugen beschrieben. Auch die dazu nötigen Instrumente werden kurz behandelt, aber ohne auf Details einzugehen.

Als weiters Anwendung der Photogrammetrie für geologische Zwecke werden Aufrisse (horizontale Parallelprojektionen) und das Uebertragen von Linien aus einer Karte in eine Photographie mit Hilfe des Autographen beschrieben.

THE GLACIATION OF SOUTH AMERICA AS RELATED TO TECTONICS (OBSERVATIONS 1939-1947)

By A. HEIM
Switzerland

ABSTRACT

During his extensive geological investigations in the High Andes between Magallanes and the Equator, executed during the years 1939-40 and 1943-47, the writer was greatly impressed by differences in the distribution of the glaciers of Pleistocene age which cannot be explained by changes of climate alone.

In Southern Patagonia, especially the region of Lago Buenos Aires (lat. 47° S.), enormous moraines and interglacial deposits of the four principal Pleistocene periods were distinguished by Caldenius (1932), the first ones having the greatest extension. This is the region of general subsidence as orographically illustrated by the fjords and the fjord-like lakes.

North of Patagonia, where the Andes rise to 6000-7000 metres, the older stages are scarcely represented. In the tropical zones of Peru and Ecuador, nothing is known of older Pleistocene moraines. Only relics of the second last stage (Riss) have been found. They are overwhelmed by the Würm moraines. This is in accordance with the general Pleistocene uplift of these regions, orographically illustrated by the terraces (Puna, Altiplano, 4000 metres).

In the Pleistocene the southern Andes were higher than now, while the northern ones were lower. These differences of tectonical subsidence and uplift explain the different development of the Pleistocene glaciations. A similar view was put forward for Peru by C. Troll in 1930.

THE INITIAL CONTINENTAL GLACIATIONS OF EUROPE AND NORTH AMERICA

By W. H. HOBBS
U.S.A.

ABSTRACT

Unlike the glaciers of Alpine type, which move over a forward sloping rock bed without a mantle rock cover, the first continental glaciers of both Europe and North America have spread over land without such slopes and hence over regolith. The material ploughed up, carried forward and laid down as till has therefore had a quite different character. It is weathered rock including organic matter—soil, turf, stumps, roots and branches of trees—all cemented together into a hard, dark-colored till described often as " hard pan." Residuals of the less easily weathered crystalline rocks in this deposit are often of gigantic dimensions (forty feet and more). These have been described as saxums, to distinguish them from the faceted boulders of the Alpine glaciers. Saxums are usually glaciated on a single surface, their under side. Most generally they stay close to the glacier front and are found outrafted in ice to the outwash plain. They have been described from earlier glaciations of both North America and Europe. They have not been found except in an initial glaciation of a region.

DENUDATION AND SEDIMENTATION IN THE HUNGARIAN BASIN DURING THE CAINOZOIC PERIOD

By A. JASKÓ
Hungary

ABSTRACT

The Hungarian Basin lies between the Carpathians, the Alps and the Dinarides, forming a geological and geographical unity. The author has collected about 500 boring logs from this territory, and deals with the present subject on the basis of data drawn from these.

The upfolding of the Carpathians and the Dinarides provoked intensive erosion and, simultaneously, sedimentation in the foreland. Here were deposited Eocene flysch (3000 m.), Oligocene marine sediments (2000 m.), Lower and Middle Miocene marine sediments (2000 m.) and Upper Miocene brackish deposits (1000 m.).

More and more of these strata are missing as one approaches the centre of Hungary. Strictly, a Hungarian Basin did not exist until the beginning of Pliocene times. At that period the Central Continent sank bodily and a single kettle-shaped basin was formed. Since then, the thickest deposits have always formed, not at the base of the mountain ranges, but in the middle of the basin. The thickness of Pliocene beds exceeds 2000 m. in some places. During Quaternary times three independent areas of sedimentation were formed, the largest sloping towards the River Tisza. The thickness of Quaternary beds in the latter exceeds 350 m. The amount of sediment deposited at various periods allows certain conclusions to be drawn regarding both the degree and speed of erosion. These are summarized in the following table:

Period (Million Years)	Period or Epoch	Extent of Sedimentation (km^2)	Accumulated Sediments (km^3)	Denuded Area (km^2)	Thickness of Denuded Rock (m)	Yearly Detritus (km^3)
0·6–0·8	Quaternary	94,000	8,224,000	482,000	20	10–13
1·6–4·0	Pliocene	203,000	213,928,000	373,000	570	50–130
1·5	Sarmatian	123,000	29,729,000	453,000	65	20

At present the amount of sediment carried away by the Danube is estimated at 1 km^3 per annum.

Erosion and sedimentation thus increased rapidly from the Sarmatian to the Pliocene and have decreased gradually from the Pliocene to the present day. This is due to the almost complete cessation of crustal movements and volcanic activity during recent times.

ON SOME IRON ORE DEPOSITS OF MADRAS, SOUTHERN INDIA

By M. S. KRISHNAN
India

ABSTRACT

A group of magnetite deposits is found in the districts of Salem and Trichinopoly in the Madras Province, India, between N. latitudes 11° and 12° 15′ and E. longitudes 78° and 79°. They belong to the Pre-Cambrian sedimentary Dharwarian formations, deposited originally as banded hematite-quartzites, and later metamorphosed to magnetite-quartzites. The associated rocks are quartzites and micaceous, chloritic and amphibolitic schists, forming a conformable sequence. The ore bands are often several miles long and of varying widths, forming prominent hills. The texture of the ore is variable, but usually coarse, so that the magnetite can be easily concentrated by electro-magnet after crushing to a suitable size (10 mesh or finer). A little hematite and amphibole are associated with the magnetite.

The average ore contains well over 25 per cent magnetite and gives 35-40 per cent iron, very low sulphur and variable phosphorus (0·01 to 0·19 per cent). The reserves in the more prominent bands, to a depth of 100 ft. from the surface, are conservatively estimated at 305 million tons. Because of lack of coal in this part of India, the ores have remained unexploited, but smelting may be done by electric power.

GÉOLOGIE ET ACTIVITÉ SISMIQUE EN TURQUIE (PRÉSENTATION DE LA NOUVELLE CARTE SISMOLOGIQUE DE LA TURQUIE)

Par E. LAHN
Turkey

RÉSUMÉ

Par la Turquie passent les deux tronçons principaux du système orogénique alpin (tronçons alpide et dinaride dans le Nord et dans le Sud respectivement) englobant la vaste zone intermédiaire de l'Anatolie Centrale et Occidentale. Des unités tectoniques d'ordre secondaire caractérisées par des traits stratigraphiques et tectoniques particuliers, peuvent être distinguées dans ces tronçons principaux. Des grands dépressions remplies de terrains oligocènes et néogènes, ainsi que des masses volcaniques néogènes-quaternaires complètent le bâti du pays.

N'étant nullement en rapport avec les structures orogéniques, la sismicité du pays est déterminée par des accidents cratogéniques très bien développés, dont la formation a continué jusqu'à des temps assez récents. Dans des systèmes comprenant des failles d'âge divers, ce sont toujours les accidents les plus récents qui sont les plus actifs.

On a établi, en Turquie, cinq zones sismiques de premier rang (Egée, Marmara, Anatolie Septentrionale et Sud-Est, prolongement du Fossé Syrien), dans lesquelles des catastrophes se répètent depuis les temps les plus réculés, ainsi qu'un nombre de zones secondaires. L'activité sismique n'est pas répartie régulièrement à travers les temps; au dixneuvième siècle, c'était par exemple la région égéenne qui était très active, maintenant c'est la région nord-anatolienne.

LES HAUTES-ALPES CALCAIRES DE LA BASSE-AUTRICHE, LEUR TECTONIQUE ET LEUR POSITION DANS LES ALPES SEPTENTRIONALES

Par E. LAHN
Turkey

RÉSUMÉ

Les Hautes-Alpes calcaires de la Basse-Autriche comprennent deux nappes superposées (la nappe inférieure de la Muerz et la nappe supérieure du Schneeberg caractérisée par la prédominance de calcaires et dolomies méso-triasiques) d'une constitution stratigraphique différente et charriées ensemble (vers le Nord) sur les nappes pré-alpines.

Vers l'Ouest, dans le Salzkammergut, ce bâti est remplacé par un autre constitué par la nappe de Hallstatt (correspondant à la nappe de la Muerz) en haut et par la nappe du Dachstein (en bas) caractérisée par le développement énorme des calcaires et dolomies néotriasiques. Un équivalent de la nappe du Schneeberg manque ici.

Cette dernière réapparaît, encore plus à l'Ouest, dans la nappe de l'Inn tyrolienne pour recouvrir directement les nappes préalpines tyroliennes dont la plus haute porte ici le nom de la nappe du Lech.

Ainsi, les Hautes-Alpes calcaires Septentrionales caractérisées par la grande épaisseur de calcaires et dolomies triasiques et formant une unité morphologique (pour laquelle les vastes plateaux calcaires sont typiques) comprennent des unités tectoniques différentes dans les divers secteurs de la Basse-Autriche, du Salzkammergut et du Tyrol.

THE LARAMIDE MOVEMENT IN CHINA

By C. Y. LEE
China

ABSTRACT

In most regions of central and southern China the Mesozoic rocks are either not metamorphosed or only slightly so. Although unconformities between Triassic and Jurassic as well as Jurassic and Cretaceous strata have often been found. they probably do not indicate large orogenic movements. As the Cretaceous beds, especially in the south-western provinces, are strongly folded or thrust, orogenesis obviously took place in post-Cretaceous time. Owing to the scantiness of early Tertiary deposits, the unconformity between Cretaceous and old Tertiary beds has only been reported at very few localities. The importance of the Laramide movements has thus generally been overlooked. In fact wherever early Tertiary beds are met with, they lie unconformably upon older formations unless the latter were not folded. On the other hand the Cretaceous beds were usually folded together with underlying strata without unconformity. Therefore it is reasonable to believe that the Laramide movement (i.e. orogenic movement between Cretaceous and Early Tertiary) is a very important event in China and in some provinces it is even the main mountain-making movement.

RHYTHMIC EARTH MOVEMENTS

By R. G. LEWIS
Great Britain

ABSTRACT

In 1933 the writer drew attention to the fact that a mathematical relationship exists between the heights of certain raised beaches above the sea, and some river terraces above their river bed. Later work is quoted; and a mechanism of very slow earth-waves is concluded to have been responsible for these features and for several other classes of geological and geographical phenomena, including rhythm in sedimentation, " deeps," and river capture. While it is acknowledged that merely circumstantial evidence is forthcoming, it is pointed out that such evidence is the stronger when various diverse phenomena are explicable on the basis of a single simple mechanism.

RESEMBLANCES BETWEEN MOINE AND " SUB-MOINE " METAMORPHIC SEDIMENTS IN THE MORAR DISTRICT OF WESTERN INVERNESS-SHIRE (SCOTTISH HIGHLANDS)*

By A. G. MacGREGOR
Great Britain

ABSTRACT

In Morar, cataclastic sutured quartz-mosaic, foliation oblique to folded bedding, abundant large grains of yellow epidote and conspicuous haematitic spots are said to be characteristic of the " Sub-Moine " metamorphic sediments (especially psammitic sediments). The first three features are apparently regarded as diagnostic of " Sub-Moine " psammitic rocks; further, it has been inferred that the " Sub-Moine Series " is separated, by a discordance, from overlying (and much younger) Moine metamorphic sediments in a different metamorphic state (Richey and Kennedy, 1939).

The writer claims that (1) all the above features can be found locally in the adjacent Moine Series; (2) at least locally (where re-investigated) no sign of discordance can be detected: on passing downwards from the Moine Lower Psammitic Group into rocks previously mapped as the outermost psammitic zone of the " Sub-Moine," there is no sudden change in lithology, in tectonics, or in metamorphic state.

Part of the supporting evidence is afforded by a new variety of calc-silicate rib (" Arnipol type ": non-garnetiferous quartzo-feldspathic rocks rich in granular epidote and with some pale-green porphyroblastic hornblende) which has been found in the two lowest subdivisions of the Moine and in adjacent psammitic rocks previously assigned to the " Sub-Moine."

In the present state of our knowledge it seems possible that all the " Sub-Moine " metamorphic sediments may constitute a concordant lower part of the Moine Series which, in the core of the Morar Anticline, contains hornblendic orthogneisses (cf. Phemister, 1948, p. 20).

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* Communicated with the permission of the Director of the Geological Survey and Museum.

DISCUSSION

W. Q. KENNEDY said that Dr. Richey and he had created the " Sub-Moine " group on structural grounds. They found they could map typical Moine schists and then they eventually came to a line. If they looked back from that line to the Moines, the sequence was regular, but looking into the core of the anticline it was not. Within the line was a lower structural group of rocks. Associated with these rocks were siliceous granulites like those of the Moines, but there were also other types unlike any seen in the Moines. There were hornblendic orthogneisses, originally igneous rocks. Nowhere in the Moines were there such great bodies of igneous rocks. In addition there was a great variety of other rocks identical with Lewisian orthogneisses to the north. The speaker and Dr. Richey thought the whole complex might be of Lewisian age. That conception was based on structural and field considerations. Undoubtedly there was a lower tectonic unit of some kind. The tectonics were absolutely different from the overlying Moines. In the plunging northern part of the Morar anticline below the homogeneous sequence of the Moines there was a syncline of " Sub-Moines "; the hornblendic rocks occupied two horizons.

Also, characteristically, the " Sub-Moine " rocks were characterized by microscopic evidence of crush. Of course, if any psammitic rocks were crushed, the effect was the same. But throughout the Moines, evidence of widespread crushing was lacking. They had therefore talked of a completely different metamorphic history; in doing so, they spoke loosely. They meant an essentially different tectonic history; one set was intensely crushed, the other was not. The area examined by Dr. MacGregor was one which was difficult to interpret, and the speaker preferred to rely on the evidence from less complex ground. Dr. MacGregor had raised the question as to whether there were Moine elements incorporated into that series. If the " Sub-Moines " were proved to contain true Moinian elements, there was an extremely interesting structural problem, which also arose at Glenelg. The speaker was personally prepared to believe that this was the case. If so, there could be in that area a series of Lewisian gneisses, and perhaps a horizon of Moines, still lower than anywhere else, as well.

E. B. BAILEY said that still further north-west was the Moine thrust. Above it one would expect to find Lewisian associated with the Moines with intense shearing, and so in the Morar anticline one would expect to find, above the Moine thrust, the Moines and Lewisian in a sheared condition. It was quite understandable that there might be Lower Moines associated with the Lewisians, the Lewisians being on the " Peach, Clough, Bailey, Tilley view " in great structural slices; hence the complication.

C. E. TILLEY said that the problems raised by Dr. MacGregor's paper had clearly to be considered in the Glenelg region to the north. There indubitable Moine sediments lying stratigraphically above the Moine conglomerate were to be found in a similar sheared condition to the rocks of the " Sub-Moine " of Morar. At the same time, he was ready to accept evidence for the presence of Lewisian orthogneiss in the Morar area. Professor Kennedy had forwarded to him specimens of acid gneisses from the north shore of Loch Nevis which were so closely comparable to acknowledged Lewisian gneiss in the Glenelg district that there seemed little doubt of their identity. It seemed probable that the " Sub-Moines " of Morar were indeed Lower Moines, in part with associated Lewisian, and that their dislocated state was to be attributed to their closer proximity to the underlying Moine Thrust.

A. G. MACGREGOR said that he hoped his observations would be of use to those engaged on research on the metamorphic rocks of the Western Highlands. His paper dealt mainly with resemblance between Moine and " Sub-Moine " psammitic rocks, and did not include a discussion of the evidence of recumbent folding in the Morar anticline.

In reply to Professor Kennedy the author said that he agreed that the " Sub-Moine " rocks represented a group structurally and stratigraphically below the Moine Series, and that the psammitic rocks of the " Sub-Moines " differed somewhat in general character from the psammitic rocks of the Moines. At present, however, he was not prepared to agree that all rocks of the " Sub-Moine " hornblendic group were undoubtedly Lewisian; there appeared to be possible resemblances to hornblendic rocks described by Professor Read from the Moinian of Sutherland. He was glad to hear that Professor Kennedy now suggested, as a working hypothesis, that the " Sub-Moine " psammitic group might represent Moinian rocks in which hornblendic Lewisian was intercalated as a result of tectonic movements, including slides. This suggestion seemed to represent definite and very welcome advance towards agreement on many of the points of issue; it would account for the local presence or absence of cataclastic texture (sutured quartz) both in the " Sub-Moines " and Moines of the Morar district.

In reply to Sir Edward Bailey the author expressed agreement that the prevalence of cataclastic texture in the " Sub-Moines " might well be connected with the presence of the Moine Thrust at no great depth.

The author noted with satisfaction that while Professor Tilley's observations in the Glenelg district strengthened Professor Kennedy's Lewisian correlation of hornblendic rocks, they also gave support to the author's own contention that cataclastic texture (sutured quartz) occurred in the Moine wherever local tectonic conditions had favoured its development. Professor Tilley had asked the author in conversation if the epidote in the calc-silicate ribs of Arnipol type might be recrystallized clastic epidote, rather than epidote produced at the expense of plagioclase feldspar. The author stated his provisional belief that much of the epidote so prevalent in the " Sub-Moine " psammitic rocks, as well as in calc-silicate ribs of Arnipol type, might well be of clastic origin; in fact, the prevalence of epidote appeared to support the correlation of epidotic Torridonian rocks with the so-called " Sub-Moine " metamorphic sediments adjacent to the lower psammitic group of the Moine.

O. HOLTEDAHL said that he would like to mention that in the area of highly metamorphic sparagmites in Norway—rocks that had so much in common with Moinian ones—the succession above the basal gneiss complex might vary from place to place because of the considerable tectonic movements. As had been pointed out in the paper read by himself at a previous meeting, it was a characteristic feature for certain districts that sedimentary masses above the basement gneiss were of a more highly metamorphic character in their lower part than at higher levels.

PALÉOGÉOGRAPHIE DU BASSIN FERRIFÈRE LORRAIN

Par P. L. MAUBEUGE

France

RÉSUMÉ

L'auteur a reconnu le faciès côtier de la formation ferrifère lorraine à sa bordure septentrionale. Dans les différents bassins du gisement il a rencontré des indices paléontologiques, stratigraphiques et pétrographiques qui le conduisent à penser que la formation est déposée dans des eaux peu profondes. Les communications avec la haute mer étaient intermittentes; à chacune de celles-ci s'arrétait le dépôt de l'oxyde de fer. Celui-ci a son origine dans la destruction des grés triasiques constituant alors la couverture des deux massifs émergés: Massif Ardennais au Nord, Massif Vosges-Schwartzwald à l'Est. Les conditions climatiques particulières expliquaient un lessivage intensif par les eaux de pluie de ces reliefs exondés.

Le jeu de la subsidence explique a la fois les épaisseurs énormes de la formation dans certains bassins et les enfoncements rhythmiques du fond marin.

Un calcul approximatif trés grossier montre qu'il n'est pas nécéssaire d'attribuer une surface énorme aux massifs générateurs du fer, le Grés des Vosges se révélant actuellement comme d'une richesse sensible en oxyde de fer. La précipitation de ce corps est d'ailleurs constatée actuellement dans les cours d'eaux vosgiens, à la suite de réductions par les matières organiques.

ON PALEOZOIC ROCKS IN THE GIESECKE MOUNTAINS (GAUSS PENINSULA), NORTH-EASTERN GREENLAND

By WOLF MAYNC

Switzerland

ABSTRACT

(*Published in full in* Meddelelser om Grønland, *Copenhagen*, Band 114, no. 2, 1949.)

The pre-Permian foundation of the Giesecke Mountains and adjacent areas is chiefly composed of Upper Devonian clastics which disclose several major orogenic cycles, the initial synorogenic facies of each being marked by a sharp angular unconformity and by conspicuous boulder-beds.

At Cape Franklin these Old Red sediments are intimately penetrated by alkali rhyolites, spherulitic quartz rhyolites, sanidine-bearing rhyolites, etc. Up to now these magmatics have been considered to be Tertiary in age. They occur, however, as reworked pebbles in the overlying Devonian series. Furthermore, the pile of Devonian sediments and the hypabyssal laccoliths and extrusives of Cape Franklin are cut by the Permian transgression-plane, proving clearly that these magmatic rocks are pre-Permian. Moreover, the Cape Franklin acidites show a strikingly close petrological resemblance to the Devonian eruptives outcropping on either side of Muskox Fjord.

In the central part of the Giesecke Mountains the rhyolitic lava flows are replaced by more abyssal intrusives (quartz porphyries, granite porphyries, granites) which pierce the Devonian strata and carry frozen-in xenoliths of Devonian sediments. Accordingly, these igneous rocks, too, are intra-Devonian (or in part even Carboniferous) in age and should not be included any longer in the " Caledonian " basement as " syntectonic " intrusions.

Relics of Upper Carboniferous plant-bearing deposits are preserved in and near a fault graben in the region of Gästis and Prospect Valley, Muskox Fjord.

JURASSIC STRATIGRAPHY OF NORTHERN EAST GREENLAND

By WOLF MAYNC
Switzerland

ABSTRACT

(*Published in full in* Meddelelser om Grønland, Copenhagen, Band 132, no. 2, 1947, *under the title*: Stratigraphie der Jurabildungen Ostgrönlands zwischen Hochstetterbugten (75° N.) und dem Kejser Franz Joseph Fjord (73°N).)

The Jurassic " Yellow series " overlaps either the marine Upper Permian or Caledonian gneisses.

The fauna of *Macrocephalitids* derived from the lowermost known Jurassic deposits is referable to the *Arctocephalites* zone (Upper Bathonian) and the *Arcticoceras-Kepplerites* zones (Lower and Middle Callovian).

A fairly rich mollusc fauna including e.g. *Parallelodon keyserlingi* d'Orb., *Pseudomonotis braamburiensis* Sow., etc. characterizes the " Keyserlingi facies " comprising the entire stratigraphical interval Callovian-Argovian.

The clastics of the " Yellow series " gradually pass upwards into sandy shales (" Gray series ") which in turn grade into the fossiliferous *Amoebites* shales of the Lower Kimmeridgian carrying *Amoebites*, *Amoeboceras*, *Rasenia*, *Aucella* (*Buchia*) *bronni* Lah., etc.

On the whole, this Jurassic sequence points towards an obvious gradual subsidence of the sedimentary basin. Locally, the clayey *Amoebites* shales may be followed again by more sandy deposits (" Kuhn beds ") of lower Upper Kimmeridgian age, yielding *Pectinatites*, *Dorsoplanites*, *Pavlovia*, etc.

Owing to the late Cimmerian block-faulting and the subsequent period of erosion, a large portion of the Jurassic sediments attaining a thickness of up to 1700 m. has locally been removed, and the boulder-beds of the Volgian " Rigi series " may overlie any of the aforementioned series with a distinct angular unconformity.

In Upper Kimmeridgian time, the East Greenland continental border underwent a strong step-faulting which resulted in a westward tilting of the different tectonic blocks. The sea completely withdrew from the whole area, with the exception of a long gulf extending along the fault scarp of inner Wollaston Foreland. Here, the synorogenic Volgian series was unconformably laid down, in the very joint of two tectonic blocks. This narrow sea-way (" Niesen Fjord ") persisted into Lower Cretaceous time (" Niesen beds ").

The Volgian boulder-beds are very poor in fossils, and the interbedded sandstone layers have furnished but a scarce *Aucella* fauna. However, on Kuhn Island these deposits show a less psephitic facies, and here the Volgian age is evidenced by *Laugeites* (*Kochina*) *groenlandica* Spath, *Pavlovinae*, *Aucella* (*Buchia*) cf. *volgensis* Lah., etc.

CRETACEOUS STRATIGRAPHY OF NORTH-EAST GREENLAND

By WOLF MAYNC
Switzerland

ABSTRACT

(*To be published in full in* Meddelelser om Grønland, Copenhagen, *under the title*: The Cretaceous beds between Kuhn Island and Cape Franklin (Gauss Peninsula), northern East Greenland.)

Beds of Infravalanginian-Rjasanian (Subcraspeditan) age with *Subcraspedites* ex gr. *plicomphalus* Sow., *S.* (*Tollia*) *stenomphalus* Pavl., *Ammonites* (non *Simbirskites*!) *payeri* Toula, *Berriasellids*, and *Aucellas* only occur within the Volgian " Niesen Fjord." Elsewhere the Cretaceous sea did not encroach upon the land until the Middle Valanginian (Polyptychitan) which is represented by conglomerates or by a fossiliferous limestone marl series carrying rich faunas comparable to those known from Speeton, Russia, etc. Diagnostic forms are i.a. *Polyptychites* spp., *Dichotomites petschoraensis* Bog., etc., *Acroteuthis*, *Aucella* (*Buchia*) ex gr. *piriformis-keyserlingi*, *concentricus*, etc. The find of a *Lyticoceras* already points towards Upper Valanginian, the red beds of which generally mark a temporary regression of the sea (stratigraphical gap comprising the Hauterivian-Barremian; locally even with a display of crustal movement).

The Aptian and Albian shales are deposits of a transgressing shoal sea and partly carry a variegated fauna including *Parahoplitoides*, *Deshayesites*, *Crioceratids*, *Lytoceras polare* Ravn, *Sanmartinoceras groenlandicus* Rosenkr., *Cheloniceras royerianum* d'Orb., *Ancyloceras*, *Neohibolites*, *Inocerami*. Part of the shale series reaching a thickness of up to 2000 m. is Albian in age which is proved by the presence of *Gastroplites* and other *Hoplitids*, *Inocerami* ex gr. *concentricus* Park., *Inoceramus* aff. *labiatiformis* Stolley, *I. anglicus* (Woods) Rosenkr., etc.

Cenomanian and Turonian are lacking in the investigated region.

The scant fauna with *Inocerami* ex gr. *cardissoides* Goldf., *Pteria tenuicostata* Roem., etc., of the " Knudshoved beds " of Hold-with-Hope has previously been assigned to the Senonian. Sediments of Upper Cretaceous age are otherwise missing and the Tertiary plant-bearing deposits unconformably overlie the Aptian-Albian series.

GEOLOGY AND GENESIS OF THE PORTUGUESE ORES OF CHROMIUM AND PLATINUM

By J. M. COTELO NEIVA
Portugal

ABSTRACT

These ores occur in the district of Bragança, related to peridotites, silicotelites and serpentines.

There are the following types of chromite deposits: (*a*) of dissemination; (*b*) of banded structure; (*c*) dispersed sackforms; (*d*) lined sackforms; (*e*) eluvial deposits; (*f*) alluvial deposits.

Chromite is associated with olivine or a serpentinous mineral. The ore contains between 20·5 and 48 per cent of Cr_2O_3.

In the chromite, Cr^{+++} has been partially replaced by Al^{+++}, and Fe^{++} by Mg^{++}.

Platinum appears in peridotites and silicotelites (magnetitites and chromitites) in small idiomorphic and hypidiomorphic crystals embodied in the chromite and magnetite and more rarely in olivine, pyroxenes and amphiboles.

The analytic results obtained for igneous rocks with platinum, in the district of Bragança, vary from 2 to 12 gr. per ton, in which a rate of 8 gr. per ton is most predominant.

By the study of the ores and its deposits it is possible to deduce that (*a*) platinum, associated with iridium, crystallized before chromite, magnetite and olivine; (*b*) a small portion of the chromite started its separation from the peridotitic magma before the silicates; (*c*) there is chromite which is contemporary with the ferro-magnesian silicates of the peridotites; (*d*) most of the chromite is of later crystallization than these ferromagnesian silicates; (*e*) there was, in certain cases, differentiation by gravity; (*f*) there must have been a chromitic rest-magma of the peridotitic magma, which was intruded after that peridotitic magma, but before the intrusion of the hornblendites and pyroxenites; (*g*) serpentinization occurred after the genesis of the magmatic chromite deposits; (*h*) there was a slight mobilization of some Cr when further granitization took place.

GEOLOGY AND GENESIS OF THE MAGNETITE DEPOSIT AT VILA COVA (SERRA DO MARÃO, PORTUGAL)

By J. M. COTELO NEIVA
Portugal

ABSTRACT

This is an important deposit due to the nature (magnetite) and reserves (some tens of millions of tons) of its ore.

The magnetitic beds, which are highly folded and directed N. 45° W., belong to the epizone. They consist of the following minerals: essential—quartz, chlorite and magnetite (authigenic and regenerated); secondary—albite, apatite, zircon and limonite (authigenic and regenerated) and biotite (dependent upon metamorphism of granitic contact); accidental—garnet, pyrite, and bismuth (these are dependent upon hydrothermal and pegmatitic veins which cross the field).

There are three types of ore estimated quantitatively: 62, 47 and 35 per cent of magnetite.

Magnetic concentration is simple. The ore should be given a grade inferior to 0·10 mm, so as to get concentrated matter practically free from P and S.

Regarding its genesis: ferriferous rocks together with clays lay at the bottom of an Ordovician sea and were covered with successive deposits. There was emergence in the Middle Devonian.

As a result of local Hercynian metamorphism, limonite gave rise to magnetite, while clays became chloritic schists.

A granitic intrusion has resulted in the formation of biotite from chlorite, and the subsequent intrusion of pegmatitic and hydrothermal veins in certain places of the field. Tertiary faults stimulated the relief of the region.

CONTRIBUTION À L'ÉTUDE DE LA STRUCTURE PROFONDE DU BASSIN DE PARIS

Par C. P. NICOLESCO
France

RÉSUMÉ

Considéré autrefois comme devant être une grandiose cuvette de dépôts sédimentaires, le Bassin de Paris est en réalité une aire critique de sédimentation et de plissement.

Des études corrélatives de nombreuses coupes géologiques de forages, point de repère contact Turonien—Cénomanien, révèlent, en effet, la présence en profondeur d'accidents tectoniques caractéristiques, brachyanticlinaux et brachysynclinaux, en général interrompus ou relayés par des inflexions d'axes, dans le sens vertical ou dans celui horizontal, sinon dans les deux à la fois, accompagnés ou non de dômes et de cuvettes.

Ces faits modifient l'importance, l'allure et les caractères des anticlinaux et des synclinaux classiques de ce bassin, tout en prouvant l'existence d'autres accidents insoupçonnés jusqu'à ce jour.

Ils peuvent être généralisés, par application à d'autres régions de ce bassin, sinon du Bassin Anglo-Franco-Belge.

Il y a là une contribution de premier plan du point de vue théorique et surtout de celui appliqué. Or, il permet de sérier les recherches tectoniques, comme conséquence des mouvements crétacés, pyrénéens et alpins, ainsi que de prévoir le succès des forages pour eau, comme intimement régis par des pareils accidents.

EVOLUTION OF THE ANDES AS PART OF THE CIRCUM-PACIFIC OROGENIC BELT

By V. OPPENHEIM
Columbia

ABSTRACT

Two stages are outlined in the orogenic evolution of the Andes. These correspond to two distinct geological provinces, the western and eastern Cordilleras of the Andes. The western cordilleras of igneous and volcanic composition preceded the rise of the eastern cordilleras of sedimentary composition. It is suggested that the western cordilleras evolved from volcanic island-arcs similar to those that form the Caribbean arc or the Aleutian arc.

A parallel is drawn with the arcs that fringe the east Asiatic coast. The unity of the circum-pacific belt is brought out by the volcanism and high seismicity centered around the Pacific.

The Andes are considered as representing a final evolutionary stage in the development of an island-arc which culminates in the formation of an igneous range separated by a geosynclinal depression from the continental land-mass and bordered by a deep oceanic trough facing the Ocean.

The existing high seismicity and volcanism of the circum-Pacific belt are regarded as expressions of deep-seated, sub-crustal convection forces which continue to be active.

TECTONIC HISTORY OF COMPRESSIONAL MOUNTAIN RANGES AS INDICATING CRUSTAL SLIDING DUE TO RADIOACTIVE HEATING

By J. L. RICH
U.S.A.

ABSTRACT

Compressional mountains of the Appalachian type reveal a tectonic history that follows a consistent pattern strongly suggesting a common genesis.

A linear upwarp is bordered by a downwarp which becomes filled with sediment from its erosion. Later, orogenic movement causes thrusting toward the downwarp. After a halt, thrusting is repeated one or more times from the same direction. Meanwhile tension develops in a region behind that from which the thrusting came. This leads to block faulting and the emission of voluminous fissure lavas. After thrusting ceases, the block-faulted area sinks.

This succession of events is explained as follows: Radioactive heating expands and melts the sub-crust in a limited area, causing a domed regional uplift on a foundation of molten or potentially molten material of no strength.

Erosion of the uplifted area causes isostatic transfer, initiating an adjacent downwarp whose sinking is accentuated as it is filled with sediment. The crust creeps slowly down the slopes of the dome and finally thrust-faults toward the downwarp and folds its sediments. Repeated movements occur, but finally crustal sliding off the dome causes tension and block faulting there and emission of lavas, after which lateral movement ceases and the domed area sinks as its magma congeals.

DISCUSSION

J. P. Marble said that recent studies by E. Gleditsch and S. Craf at Oslo (*Phys. Rev.*, 1948) indicated that:

(i) the radioactive isotope of potassium (K 40) had a greater radioactivity than earlier work had shown, being equal to or greater than that due to U+Th. Hence it was not necessary to invoke a great depth of radioactive matter to account for the heat needed; thus only a comparatively shallow zone need heat up, as postulated by Rich.

(ii) The half-life of K 40 was shorter than thought, thus more heat was available in Pre-Cambrian times, which bore out Dr. Rich's statement that " Shield Areas " were now quiescent but were formerly subject to orogenic activity.

G. M. Lees said that he wished to congratulate the author on his new approach to the principles of mountain building, and on his stimulating paper. He agreed that the great downwarps and upwarps of the earth's crust must have a deep-seated cause and the action of radioactive heating was a possible explanation, though on a more restricted scale than postulated by Joly. He wished to record his dissatisfaction with the general principle of isostasy. The great downwarps which gave rise to geosynclines were depressed through deep-seated causes and not through the load of sediments. Sedimentation would cease abruptly if sinking stopped. The elevations of mountain ranges in most cases long post-dated the compressional phase. Some sectors were uplifted and some were not, but neither gravity surveys nor general surface evidence afforded a clue at present to the fundamental causes. He was glad to note Professor Rich's disbelief in the permanence of oceans, at least for the Atlantic.

R. M. Shackleton suggested that in showing only cross-sections of the phenomena supposed to occur at one margin of the postulated magma sheets, the author did not explain the distribution of orogenic zones as seen in plan. One would expect the limits of the magma sheets to be outlined by girdles of fold structures, whereas in reality the orogenic zones seemed rather to be linear in character.

J. L. Rich, replying to a question by Dr. Shackleton as to whether one should not expect thrusting to develop on more than one side of a magma dome, said that it seemed possible that crustal creep off a magma dome might occur mainly on one side in some instances, but actually, in many cases, flowage seemed to have been more or less radially outward from an elongated magma body. Examples were the Caribbean area where thrusting seemed to have been outward in at least three directions from a formerly elevated area, now submerged beneath the Caribbean Sea; the Western Mediterranean basin; and, the speaker suspected, the plateau of Anatolia and that of Central Iran.

The size that a magma dome had to have in order that crustal creep might occur almost certainly would depend on circumstances such as thickness of crust above the magma body and the degree of doming. In the United States similar flowage on a small scale was suspected to have occurred off relatively shallow sill-like bodies having diameters of not much, if any, more than 100 miles.

THE WEALDEN IN SPAIN

By CLEMENTE SAENZ GARCIA
Spain

ABSTRACT

Over a large part of Spain—covering a triangle defined by Oviedo, Valencia and Gerona—there is found a gr disconformity, beginning with the marine sediments of the Dogger, Callovian and Oxfordian, and extending in sc places as far as the Upper Cretaceous. In some places the intermediate sediments are lacking, in others there are c tinental and lacustrine formations of the Wealden facies. The latter, which have a huge thickness in the provinces Logroño, Soria, Burgos and Santander, must have been laid down either in a large lake or terrestrially, after the mar regression in the Ebro basin.

Other regressions took place in the Bunter, Keuper, Garumnen and Oligo-miocene, but that of the Wealden ep was the greatest.

The fossil fauna is scarce, except for some reptiles and fishes.

In the present paper, details of the stratigraphy are described, following the small intermediate transgression of coralline formations of the Urgon and Aptian, which entered through the Cantabrian and Mediterranean seas, and coastal deposition of variegated sandstones with lignites and petroliferous indices of the Albian formation, marking beginning of the Upper Cretaceous transgression.

ON THE NATURE OF MAJOR TECTONIC STRUCTURES OF ANCIENT PLATFORM

By N. S. SCHATSKY
U.S.S.R.

ABSTRACT

(1) Ancient platforms (kratons) represent huge blocks, polygonal in outline. Where the edges of the kraton fo re-entrant angles, special tectonic structures are developed (*transverse marginal structures*, e.g. Great Donetz Bas Wichita System, Delaware Basin, Graben of Oslo, etc.).

(2) *Marginal basin* (=marginal deep), i.e. *lateral structures*, are found only between plates (Tafel) and surround folding zones, the shields being separated from the mountain chains by narrow *sutures*, viz. the south-eastern edge the Scandinavian Caledonides, the north-western border of the Scottish Highlands and Logan's line. The relationsh show that the *shields* and *plates* are individual tectonic units.

(3) In the interior portions of the kraton, *syneclises* (Moscow Syneclise, Michigan Basin, etc.) and anteclises (Voron anteclise, Kankakee arch, Cincinnati arch, etc.) form an irregular network; while the former are meshes, the latter app to be nooses. The anteclises represent passive, residual tectonic forms, viz. the kraton's parts that were slow in the wh downwarping of the platform.

(4) The immense length of the rectilinear borders of the platform and the great stretch of the transverse margi structures (up to 500-1000 km.), as well as geophysical data, point to the great thickness of the kraton blocks, far exceeding the thickness of the " sialic shell."

Neither the origin of the tectonic forms mentioned above, nor the structure of the kraton on the whole, can imagined on the basis of the existing conceptions. Not only the " Sial," but also the internal shells of the Earth proba took part in the kraton building. The basins and other structures have possibly originated from compaction of mat in the deep part of the kraton.

CONNAISSANCES ACTUELLES SUR LA PALÉOGÉOGRAPHIE DU BASSIN D'AQUITAINE

By D. SCHNEEGANS
France

RÉSUMÉ

La paléogéographie du Bassin d'Aquitaine a fait des progrès grâce aux forages profonds effectués dans l'avant-pays Nord-Pyrénéen pour la recherche du pétrole.

On distingue la succession des évènements suivants:

(1) Une sédimentation épicontinentale calcaréo-dolomitique et marneuse s'étend sur le domaine pyrénéen et sur le pourtour du Massif Central du Trias au Jurassique moyen.

(2) Une émersion accompagnée d'altération chimique correspond à la lacune du Jurassique supérieur et du Crétacé inférieur dans la plus grande partie des Pyrénées, exception faite de la basse Navarre (Lamare).

(3) Un jeu de tension provoque l'effondrement du domaine Pyrénéen et l'installation de la mer au Crétacé moyen. Cet affaissement s'est produit suivant un réseau de fractures et a ouvert la voie à des montées de magma ultra-basique.

(4) Ces poussées orogéniques embryonnaires déterminent un jeu de cordillères. La zone centrale des Pyrénées s'érige et une série de reliefs accidente le fond marin, les sillons se resserrent et se remplissent de matériaux détritiques arrachés aux reliefs environnants. La marge Nord Aquitaine liée vers le Nord aux Causses est le siège d'une sédimentation épicontinentale calcaire.

(5) Au fur et à mesure du comblement des filons par le flysch, la mer s'étend plus largement et le régime marin épicontinental s'installe sur le domaine Aquitain et déborde sur le faîte des Pyrénées. L'exombation progressive de l'Aquitaine se poursuit d'Est en Ouest et marque le début de la phase d'une déterminante de l'orogénèse Pyrénéenne. Plus tard, pendant le Miocène le comblement du bassin de Piémont s'opère à la fois à partir des Pyrénées et du Massif Central (Vatan).

IRON DEPOSITS IN SOUTH PORTUGAL

By J. MARTINS DA SILVA
Portugal

ABSTRACT

In South Portugal there are the following kinds of iron deposits:

(*a*) Deposits formed by concentration in magmas.
Irregular masses of magnetite included in gabbros. The ore structure is similar to that of the adjoining rock. Minerals of metasomatic replacement are absent.

(*b*) Pyrometasomatic deposits not related to contacts.
The ore bodies are lenticular masses of magnetite with pyrite that follow the stratification of adjoining rocks. These iron ores are in an Archaean series cut by eruptive rocks. They occur in crystalline limestones or at the contact of these with metamorphic schists.

(*c*) Pyrometasomatic deposits.
The iron ore occurs at the contact of crystalline limestones with diorite and is accompanied by " skarn."

(*d*) Veined deposits.
The ore is hematite and limonite with manganese oxides. The walls are formed by quartz and barite which are also the predominating gangue minerals.

(*e*) Sedimentary deposits.
Hematite ores with quartz occurring in Archaean—Pre-Cambrian rocks.

UNUSUAL THRUST STRUCTURES IN THE WILLOURAN RANGES, SOUTH AUSTRALIA

By R. C. SPRIGG
Australia

ABSTRACT

Upper Pre-Cambrian (Adelaide System) sediments in the north-western portion of the Flinders geosyncline have been deformed in a manner differing greatly from that of the rest of the folded geosyncline. The tens of thousands of feet of sediments concerned in this local deformation are dominantly slates and limestones, but include a massive quartzite formation about 6000 ft. thick. This competent formation exerted a controlling influence in the local tectonics.

During the collapse of the geosyncline great faulted sheets of the quartzite moved to the south-east, resulting in both high- and low-angle thrust faulting. North of Wichelina, one such thrust sheet has been folded back on itself, and has pinched out into a zone of massive quartz reefs. Near Mount Nor-west, about 20 miles west of Wichelina, a steep regional anticline has been sheared vertically, along its axis, and the north-eastern limb has been thrust to the south-east, producing what appears in plan as a faulted recumbent major fold. The fault shear is the locus of great brecciation and of dolerite intrusion. At South Hill, about 5 miles south-west of Wichelina, the quartzite has been dragged into steeply pitching similar folds, whereas the slates and limestones on the other side of the fault have been drawn out into the shear.

PLAGES ANCIENNES ET TERRASSES FLUVIATILES DU NORD DU PORTUGAL

By C. TEIXEIRA
Portugal

ABSTRACT

Sur le littoral du Nord du Portugal on signale l'existence d'une série remarquable de niveaux de plages, la plus haute étant à 150-160 m. d'altitude. En correspondance avec ces plages il y a, sur les rives des fleuves, des terrasses fluviatiles de même altitude.

La description sommaire de ces niveaux constitue le but principal de la communication. Comme conclusion on fera quelques considérations sur la tectonique récente du pays.

LATERITES IN NEW CALEDONIA, SOUTH PACIFIC AREA

By A. C. TESTER
U.S.A.

ABSTRACT

The typical laterites of New Caledonia occupy the high slopes and plateaux above 560 ft. elevation. The iron oxide content is between 28 and 38 per cent with the major portion showing 32-33 per cent. The parent rock of the laterite is serpentine which was altered from the large peridotite body which forms the main mass of the island. The thickness of the laterite attains 36 to 38 ft. in some of the remnant high plateaux but the usual thickness of 12-18 ft. is found as a veneer on the upland slopes. At the base of the laterite the rock grades downward into brown weathered serpentine which contains the concentration of the nickel silicate garnierite. Iron oxide deposits which are not true laterites are found at several levels below 560 ft. These deposits are composed of pellets of several millimeters size and some silt, derived from the upland laterites and deposited in embayments and over coral reefs during stands of the sea that developed eustatic benches. In some aspects these terrace deposits are mistaken for true laterites as the composition is essentially the same, but detailed study shows evidence of transportation and sorting by streams and waves, and a variety of underlying rocks that could not produce the concentration of iron oxide by weathering *in situ*.

Another special condition of weathering of serpentine produced blanket-like deposits of pure magnesite. Examination indicates that such deposits are sedimentary and though derived from the adjacent areas of serpentine, were precipitated in shallow basins enclosed by coral reefs.

ADDITIONAL DATA ON SPLITS AND WASH-OUTS

By A. A. THIADENS and J. I. S. ZONNEVELD
Netherlands

ABSTRACT

(*Published in full in* Mededelingen van de Geologische Stichting, Nieuwe Serie, 1950).

Studies concerning splits and wash-outs in Carboniferous strata in the Netherland, by Thiadens and Haites (*Med. Geol. Stichting*, Series C.II-1-1 Maastricht, 1944), raised some new views concerning the genesis of the Coal Measure sediments.

Maps, sections and block-diagrams demonstrate some of the new data: (*a*) some small wash-outs, partly synchronous with the peat, partly post-peat; (*b*) some greater synchronous wash-outs and the beginning of splits; and (*c*) an example of the action of the Rhine in the low lands of Holland.

The relation between the small wash-out and the petrographical composition of the coal is reviewed.

The described phenomena—the splits and wash-outs, the variable facies of the roof of a coal seam, the variations in thickness of coal and country-rock layers, the coincidence of wash-outs and thick development of country rocks above, the wash-outs in the country-rocks, etc.—are explained as due to:—

(1) generally uniform subsidence (not a constantly intermittent subsidence);
(2) the important part played by fluviatile action in Carboniferous sedimentation;
(3) differential compaction of the various sediments.

UNE FORMATION PHOSPHATÉE À BISSAU (GUINÉE PORTUGAISE)

Par A. SOUSA TORRES
Portugal

RÉSUMÉ

Plusieurs échantillons géologiques, recueillis en 1945 à Bissau et à ses environs par l'ingénieur portugais M. Henrique O'Donnell, ont fait l'objet d'une note préliminaire (A. Torres, H. O'Donnell, P. Soares: Quelques témoins géologiques sur la Guinée Portugaise, *Bol. Soc. Port. Ci. Nat.*, Lisboa).

Depuis, j'ai fait l'étude micrographique des échantillons calcaires biogéniques de la même provenance, tout d'abord dans le but d'identifier les foraminifères, dont la plupart j'attribue à l'Éocène.

D'ailleurs, j'ai remarqué que toutes les lames minces de ces calcaires avaient des granulations, plus ou moins nombreuses, de phosphate de chaux, selon les niveaux de la série lithologique. Des analyses chimiques faites par B. Edmée Marques, professeur à la Faculté des Sciences et par Regina Grade, ont montré que les teneurs en phosphate sont suffisantes pour éveiller l'intérêt des nouvelles recherches sur ces calcaires.

SEDIMENTATION OF PERMO-TRIASSIC SANDSTONE IN TATRA

By M. TURNAU-MORAWSKA
Poland

ABSTRACT

The deposition of Permo-Triassic sandstones in Tatra probably took place in a desert basin of internal drainage. Most of the rocks were deposited in water, but some are of aeolian origin. Finally, the whole series was intensively silicified.

THE STRUCTURE OF THE IBERIAN PENINSULA AND ITS RELATIONS WITH EUROPE, AMERICA AND AFRICA

By FERNANDO REIG VILAPLANA
Spain

ABSTRACT

(*Published in full in* Asesoria Geologica da Obras Publicas, Madrid, 1948.)

This paper provides the groundwork for further investigations of the structure of the Peninsula, on the basis of the theories of continental drift and sub-crustal convection currents.

The first section is concerned with the geographical distribution of the different geological formations, and the orogenic cycles, unconformities and situation of the effusive rocks of different ages throughout the Peninsula.

The second section describes the present structural units of the Peninsula, directions of folding, great faults and basins.

The third section deals with the stratigraphical relation between the Peninsula formations and those of the same age of western Europe, eastern America and northern Africa; with the distribution of the different facies; with the situation of the effusive rocks and their relations with the regional structure; and with some special submarine features and their geological and structural explanation.

In the fourth section, the structural history of the Iberian Peninsula is described; from an origin between the south-west of the British Isles and the east of North America, to its present situation. The phases of its evolution and the formation of the Bay of Biscay, the Ebro basin, the two basins of Castille, the Balearic Islands, the Betis Valley, and the Strait of Gibraltar are explained.

VARIOLITES ET SPILITES: COMPARAISON ENTRE QUELQUES PILLOW-LAVAS ALPINES ET BRITANNIQUES

Par M. VUAGNAT
Switzerland

RÉSUMÉ

Les découvertes récentes, dans les Alpes franco-suisses, de pillow-lavas fréquemment spilitiques appellaient une comparaison directe de ces roches avec celles des gisements classiques de Grande-Bretagne afin d'étudier les correspondances existant entre la composition spilitique et les structures arborescentes, variolitiques et ellipsoïdales.

L'examen sur le terrain des principaux affleurements de pillow-lavas tertiaires (Mull), dévoniennes ou carbonifères (Devon, Cornwall), ordoviciennes (Ayrshire), dalradiennes (Argyll) et précambriennes (North Wales: Mona Complex) indiquerait que seul le dernier groupe possède les structures franchement variolitiques (sens français du mot) si fréquentes dans les pillow-lavas alpines. Une étude microscopique étayée par trois analyses chimiques nouvelles révèle une resemblance frappante entre les roches galloises et alpines (textures, structures, architecture et constitution des coussins, associations, effets du métamorphisme, etc.). Plusieurs observations démontreraient l'origine primaire de minéraux généralement considérés comme secondaires (chlorite, carbonate, etc.) confirmant la nature très particulière, épimagmatique, du magma spilitique. Certains spécimens sont aussi frais que mainte diabase alpine du Crétacé supérieur. On peut relever que la chaîne " monienne " est une des rares chaînes, actuellement connue, de style tectonique alpin pennique.

DISCUSSION

E. B. Bailey said that he himself never used the term spilite, which he regarded as a most unsatisfactory term. Some people now said that some pillow lavas were intrusive.

M. Vuagnat replied that he thought that most pillow lavas were true lavas, though some might perhaps have entered a few metres into soft mud.

E. B. Bailey remarked on the interest of the author's conclusions that there were no true variolitic structures except in Anglesey, though he admitted that a variolitic tendency was not rare. There was also the interesting conclusion that the exterior of the pillow differed from the interior. In Scotland cases were known where lava flowed over carbonaceous sediments, in contact with which the lava was changed to a white trap.

A. K. Wells referred to a paper he had written many years ago, on the problem of the spilites, in which he had stressed the fact that spilite and pillow lavas were not synonymous terms. He referred to the omission from the author's list of some of the most striking British occurrences, viz. those of Ordovician (Llanvirnian-Llandeilian) age in the Dolgelly district of North Wales. Some of these were typical spilites but others contained fresh augite and a more basic plagioclase. In textural detail they closely resembled certain of the Tertiary basic dyke rocks of Western Scotland. Both feldspar and pyroxene participated in the characteristic radial groupings (termed variolitic in England) exactly as illustrated by the author.

O. T. Jones remarked that the most important evidence of intrusive pillow lava was that of Benson in New Zealand. The pillow lavas there had relations as clearly intrusive as any that could be wished. They were probably intrusive into muds. Harker clearly had a similar notion. In recent work rocks had been mapped which had texture just like that in the slide shown by M. Vuagnat. There were fine pillows, with vesicular rims, between all kinds of baked muddy sediments; and they were clearly intrusive bodies. One quarry showed a perfect pillow lava passing upwards into dolerite which had intrusive relations.

THE DEVELOPMENT OF CLIFF SLOPES

By A. WOOD
Great Britain

ABSTRACT

The series of changes through which an ideal cliff face passes, under given intensities of marine and sub-aerial denudation, is discussed. In practice, a single cliff may display widely differing stages in the cycle of events. It is shown that the actual form of cliff slopes is due to a complex of factors among which lithological and structural control rank high. The recognition of a theoretical succession of events makes it possible to ascertain the developmental history of each portion of a cliff face, and in some cases to recognize a series of partial cycles.

QUATERNARY GLACIATION IN SOUTH-WEST CHINA AND ITS BEARING ON GOLD PLACERS

By Y. S. WU

China

ABSTRACT

At various localities in South-west China well known for their Quaternary glacial phenomena, such as the flanks of the Nanling Range, the environs of the Yunnan-Kweichou Plateau and Kwangsi Platform, the border of Szechuan Red Basin and the marginal belt of the Sikang Highlands, there are also well pronounced gold placers. High above these areas are projecting peaks, with spillway-gaps, hanging valleys, long straight U-shaped troughs, funnel-shaped cirques and many paternoster basins at altitudes of about 1,000 m. above sea level. In the surrounding lowlands are erratics, hummocky rolling hills, festoons of moraines and patches of varve-clay as well as sheets of out-wash sands and gravel, 1-20 m. thick, composing in most cases the " pay-dirt."

On stratigraphical as well as physiographical evidence, the glaciation in south-west China may be correlated with that of Pleistocene age in Europe.

Some of the placer gold sands are fine-grained, evenly distributed, well water-worn and sorted; others, as in moraines or in the kettle holes and crevasses, are often coarse-grained, sub-angular sands, extraordinarily rich in gold.

The placers are derived from veins of gold exposed in the high mountains. Glaciers plucked and quarried the valley walls and floors, and scooped and bevelled the projecting veins. Frost weathering loosened the veins from the country rock and the ore from the gangue. Pounding, as the ice descended from the cirque or hanging valley to the main trough, and grinding and abrasion as the glacier moved, together disintegrated the vein. In addition to gravity sorting of the ore sands, fluvial processes of the super-, intra- and sub-glacial drainages helped to produce concentrates in the sands of the outwash plain. Ore sands tended to lodge in kettle-holes or fissures, or other openings which the ice tongue met. Rich pockets are often found in crevasses high on the mountain ridge.

Iron staining is common on the faceted tongue-shaped pebbles in the " pay-dirt," and probably resulted from lateritization during an inter-glacial period. It is used as a guide in prospecting for placers.

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GEOLOGICAL ENVIRONMENT AND SEDIMENTARY PETROLOGICAL PROVINCES

By J. I. S. ZONNEVELD
Netherlands

ABSTRACT

A sedimentary petrological province is a complex of sediments which by their geographical distribution, age and origin form a natural unit. Provinces occur in marine as well as in continental sands. Their properties, however, can differ according to the " facies " in which they were formed.

In the seas, most of the sediments are supplied by rivers and spread out by ocean currents. The sediments originating from one river form a " pure " province that can interdigitate with those of other rivers.

In the river itself, however, one cannot speak of a pure province, each tributary supplying new sediment to the main river. " Pure " provinces would only be found in the upper parts of the source rivers. Only in deltaic plains and the lower courses, provinces of some homogeneity and extent can be found.

In aeolian deposits relatively vast provinces can be formed if the sediment is supplied by only one formation, or a volcano, and if the material has been fully mixed up (e.g. as a dust at great height), otherwise the characteristics of the provinces can be compared with those of fluvial provinces.

ASBESTOS AND TALC RESOURCES OF INDIA

By L. ZUTSHI
India

ABSTRACT

The paper discusses the economic importance of the above and their increasing consumption in India, and the still greater future demand likely to be caused by the contemplated industrial development.

A description of the geology, mode of occurrence, form and genesis of various ore deposits in the following important fields has been attempted.

(1) Rajputana Area: This includes steatite deposits of Jaipur, Udaipur, Sirohi States and Godhra District; talc occurrences in Idar, Udaipur and Dungarpur States; tremolite deposits in Udaipur, Dungarpur and Idar States and chrysotile in Dungarpur State.

(2) United Provinces: talc occurrences in Hamirpur and Jhansi Districts.

(3) Central India: amphibole asbestos in Bhandra District; talc in Jubblepore, Katni, and Bijwara State, Central Provinces.

(4) Bihar and Orissa: talc occurrences in Singhbhum District and west of Bara Kadel, Seraikala State; amphibole asbestos deposits of Bara Bana, Seraikala State.

(5) Mysore: amphibole deposits of Hassan and Bangalore Districts.

(6) Madras: chrysotile deposits of Brahmanpalli, Cuddapah; talc occurrences in Nellore, Salem and Kurnool Districts.

The paper concludes with comments on their economic development and commercial utilization.

THE GEOLOGY AND MINERALOGY OF CLAYS

Three meetings on the geology and mineralogy of clays were arranged in conjunction with the Clay Minerals Group of the Mineralogical Society of Great Britain and Ireland.

The successive Chairmen at these meetings were as follows:-

August 26th	Dr. G. W. Brindley Dr. S. Hénin
August 27th	Professor R. E. Grim Professor J. J. de Lange
August 30th	Dr. W. Campbell Smith Dr. S. Hosking

The Secretary for these meetings was Dr. D. M. C. MacEwan.

Titles and abstracts of papers which were presented are printed on the following pages.

THE ILLITE CLAY MINERALS

By R. E. GRIM and W. F. BRADLEY
U.S.A.

ABSTRACT

Optical, chemical and differential thermal analytical data are presented for a series of selected clay minerals and related specimens, chosen to illustrate the relationships of the illite group of micas to several of the closely similar clay mineral materials from which they are not always readily differentiated.

The illites are fundamentally a fine-grained manifestation of the muscovite crystallization, and as such are to be distinguished from those more basic members related to the (octaphyllite) biotites. Also, as micas, for which the crystallization is three-dimensionally static, the illites are to be distinguished from the frequently encountered mixed-layer crystallizations that comprise associated individual layers of mica and montmorillonite intergrown, and which consequently exhibit quite similar chemical and optical properties. Bravaisite and sarospatite are shown to be examples of mixed layers of illite and montmorillonite.

Attention is also directed to the influence upon analytical data of small admixtures of some of the frequently associated minerals.

NUOVO TIPO DI ILLITE-IDROMICA IN GIACIMENTO IDROTERMALE DI BASSA TEMPERATURA

Por C. ANDREATTA
Italy

RIASSUNTO

A Capalbio (Orbetello, Toscana), sotto uno strato di argille halloisitiche e montmorillonitiche, si trova uno strato di un minerale micaceo più povero di alcali e più ricco di acqua dei tipi chiamati illiti. Il minerale è molto puro ed il giacimento è di origine idrotermale di bassa temperatura; lo strato poggia sulle filladi.

Il minerale è studiato microscopicamente, roentgenograficamente, chimicamente. Si dimostra che è derivato dall' alterazione idrotermale delle miche muscovitiche e biotiche che costituiscono in prevalenza le filladi. Il minerale micaceo, più che un termino unico, è da considerare una mescolanza di diversi termini a composizione chimica molto prossima.

L'autore ritiene che tutti i minerali di tipo micaceo noti come idromiche, illiti, damouriti, ecc. siano mescolanze varie di diversi termini di due serie, una alluminifera e l'altra magnesifera, che terminano ambedue con la montmorillonite (eventualmente beidellite):

$$\begin{array}{lllllll} \text{muscovite} & \rightarrow & \text{Al-illiti} & \rightarrow & \text{Al-idromiche} & \rightarrow \\ \text{biotite} & \rightarrow & \text{Mg-illiti} & \rightarrow & \text{Mg-idromiche} & \rightarrow \end{array} \left\{ \begin{array}{l} \text{montmorillonite} \\ \text{(ev. beidellite)} \end{array} \right.$$

Considerando l'analogia dei reticoli cristallini dei termini di queste due serie, si puo ammettere l'esistenza di miscele isomorfe fra muscovite e montmorillonite e fra biotite e montmorillonite (eventualmente beidellite).

A SCOTTISH ILLITIC MATERIAL

By R. C. MACKENZIE, G. F. WALKER and R. L. HART
Great Britain

DISCUSSION FOLLOWING THE THREE PRECEDING PAPERS

The discussion on the first two papers began and ended with questions of nomenclature. In reply to D. M. C. MacEwan, who raised the question of " illite " and " hydromuscovite," R. E. Grim repeated his opinion that " illite " should be a general name for all clay micas, and suggested that the introduction of specific names for such minerals, though eventually essential, was not yet opportune. G. Nagelschmidt considered that " hydromuscovite " should be used for crystals of 20μ or larger and " illite " for fine grained material. D. M. C. MacEwan also wondered if any absolute distinction could be maintained between " illite " and " bravaisite." Many illites showed " tailed " basal reflections indicating that part at least of the water was interlamellar. R. E. Grim, in his reply, said that he had favoured the idea that the illites contained oxonium ions replacing potassium, and G. Nagelschmidt said that this idea fitted dehydration curve data.

Dr. Philippi raised the question of quantitative analyses, asking whether X-ray or differential thermal analyses were better. R. E. Grim preferred the former, but considered that many methods were needed with complicated mixtures. G. W. Brindley considered that orientation of the crystallites constituted a serious difficulty in quantitative X-ray work. D. M. C. MacEwan suggested that the principal difficulty at present was that the different types of clay minerals were not adequately characterized.

C. Andreatta, in reply to a question from G. F. Walker said that X-ray evidence was not available to distinguish between illites derived from muscovite and biotite. R. E. Grim asked what was the distinction between illites and hydromicas, and was informed that the latter were poorer in alkalis and richer in water.

THE PRINCIPAL CLAY MINERALS IN CERTAIN REFRACTORY AND BOND CLAYS

By A. L. ROBERTS and R. W. GRIMSHAW

Great Britain

ABSTRACT

A previous study mainly by differential thermal analysis of the mineral constitution of a series of commercial fireclays and bonding clays, showed the principal clay mineral to differ fundamentally from kaolinite, and in many respects closely to resemble halloysite, although not completely identical with it. Subsequent X-ray studies by G. W. Brindley suggested that it was intermediate in character between kaolinite and halloysite, differing from them in the degree of structural randomness.

The original work was carried out using commercial clays with 40–50 per cent of this mineral, and the next stage in the investigation was its separation in as pure a state as possible. This has now been achieved by centrifuging clay suspensions, and a few grams of the mineral of more than 90 per cent purity have been isolated.

Results will be given of a number of tests on this material, including chemical analysis, differential thermal analysis, optical data, dehydration and rehydration studies, electron microscope and X-ray examination. The results confirm that the mineral can be classified with the kaolinite group, but it has properties distinctly different from any recognized member of the group, and must be considered as a new mineral.

CHANGES PRODUCED IN KAOLIN MINERALS BY GRINDING

By A. WESTERMAN and A. L. ROBERTS

Great Britain

ABSTRACT

In view of Laws and Page's conclusion (1946) that prolonged dry grinding of kaolinite results in the formation of a new permutite-like mineral, and of the discovery of a kaolinite group mineral of very small particle size in fireclays, it was thought that an investigation of the changes produced in minerals of this group by grinding might help to elucidate the character of the fireclay mineral.

Samples of dry and wet kaolinite and halloysite were ground for varying periods and examined by differential thermal analysis and dehydration tests. Small specimens were prepared for X-ray and electron microscope examination. Transverse breaking strength and particle size distribution tests were also carried out.

Significant changes were found to take place, the minerals beginning to lose their crystalline character after short periods of grinding. Kaolinite and halloysite were almost non-existent after 144 hours dry grinding. However, the apparently amorphous material appeared to have some residual structure as, after the endothermic peak on the thermal curve near 600° C. had disappeared, the exothermic peak at 980° C. was unaltered.

STRUCTURAL RELATIONSHIPS IN THE KAOLIN GROUP OF MINERALS

By G. W. BRINDLEY

Great Britain

ABSTRACT

The common structural unit of these minerals is the hydrated aluminosilicate layer of composition $Al_2O_3.2SiO_2.2H_2O$. Different *regular* arrangements of these layers produce the well-defined minerals nacrite, dickite and kaolinite. Irregular arrangements produce a continuous series of minerals from kaolinite to metahalloysite. Kaolinite is triclinic and contains one layer per unit cell. In metahalloysite, successive kaolin layers are randomly displaced with respect to both the *a*- and *b*-axes in the plane of the layer. In the kaolin mineral found in many fireclays, the kaolin layers are displaced randomly in the *b*-direction with displacements of $nb/3$, where n is integral.

The effect of wet and dry grinding of kaolinite and halloysite described by Westerman and Roberts has been examined by X-rays. Dry grinding of halloysite and wet grinding of both minerals produces little structural change but dry grinding of kaolinite produces a progressive destruction of the crystal structure; the layers themselves persist longer than the interlayer regularity of the original mineral.

DISCUSSION FOLLOWING THE THREE PRECEDING PAPERS

In reply to a question by R. E. Grim about the moisture content of the kaolinite samples used, R. W. Grimshaw said the tests were done on clay which had been dried from a fixed moisture content. He agreed with R. E. Grim that there would be difficulty in correlating such tests with plastic bonding properties.

J. J. de Lange asked G. W. Brindley if fireclays could not be considered as stages in the synthesis of kaolinite, rather than stages in its destruction, and was informed that attempts to form a more ordered structure by heat-treating metahalloysite had failed. He suggested that steam treatment might be more successful.

W. Davis suggested that the bonding properties of the clay used by R. W. Grimshaw might have been appreciably altered by the presence of a few percent of sericitic clay, but R. W. Grimshaw, G. W. Brindley and A. L. Roberts all thought it impossible that more than a trace of micaceous mineral could have been present.

As regards the nomenclature of these minerals, E. H. Beard pointed out that the name " mellorite," which was suggested for the fireclay mineral, had already been applied to an artificial ferric calcium silicate (*Min. Mag.*, 1943, 26, 330). D. M. C. MacEwan suggested that, in view of the evident complexity of the minerals related to kaolinite, it would be convenient to introduce the name " kaolinoid " for any member of this series, a suggestion which was supported by A. L. Roberts. S. Hénin suggested that a discussion was necessary on the general question, how far separate names are desirable for constituents of a continuous series.

G. M. Gad reported the presence of the new fireclay mineral in a range of transported Egyptian clays. A series of such minerals, ranging from halloysite to kaolinite was observed, and sometimes a mixture of two in one specimen, as shown by the doubling of the differential thermal peak. He also mentioned that the exothermic peak of kaolin minerals is reduced in presence of alumite.

TRANSFORMATION DES MINÉRAUX DE LA FAMILLE DES MONTMORILLONITES EN PHYLLITE à 10 Å

Par S. HÉNIN

France

RÉSUMÉ

Les feuillets constitutifs de la montmorillonite et de certains micas paraissent très voisins, sinon identiques. On pouvait donc espérer passer de l'un â l'autre de ces minéraux par un traitement convenable. En effet, une montmorillonite ou une nontronite soumises à l'action de KOH à l'ébullition, ont donné une phyllite dont l'équidistance â l'air était 10Å et qui ne se gonflait pas en présence d'eau. Cependant, après traitement par des ions Ca, les substances ainsi obtenues se sont plus ou moins réouvertes et ceci assez aisément, tandis que dans les mêmes conditions, la muscovite finement broyée est beaucoup plus stable.

EXPÉRIENCE SUR LA FORMATION ET L'ÉVOLUTION DES CHLORITES ET DES VERMICULITES

Par S. CAILLÈRE

France

RÉSUMÉ

Des résultats antérieurs ont montré qu'il était possible de préparer une substance voisine d'une vermiculite ou d'une chlorite en précipitant le magnésium au contact de la montmorillonite. Le nickel et le cobalt ont fourni des résultats voisins. Mais les tentatives faites pour généraliser cette transformation en utilisant des ions Fe^{++}, Fe^{+++}, Mn et Al ont été moins heureuse. Dans certains cas, cependant, après vieillissement à l'étuve à 100°, des substances présentant les caractères d'une phyllite stable à 14 Å ont pu être obtenues.

Par contre l'altération en milieu acide d'une chlorite finement broyée n'a pas conduit à l'obtention d'une montmorillonite.

DISCUSSION FOLLOWING THE TWO PRECEDING PAPERS

In reply to a question from R. H. Schofield regarding the charge on the constituent layers of chlorite, S. Hénin said that the brucitic layer in their product was not considered to be attached to the montmorillonite layer by an excess of charge, as in natural chlorites.

B. S. Emódi said that on repeatedly wetting and drying a K-saturated montmorillonite, it gradually loses its microscopic swelling properties and much of its base-exchange capacity, and S. Hénin agreed with her that this could be due to a similar transformation to that reported by him.

G. F. Walker reported the very high base exchange capacity of natural vermiculite, and the variation of the basal spacing from 10·6 Å for the NH^{4+} saturated mineral to 14 Å with Mg^{++}. Hydrobiotite, according to R. C. Mackenzie, was probably an interstratification of about 45 per cent vermiculite with 55 per cent biotite.

ALTERATION OF THE PROPERTIES OF BENTONITE BY REACTION WITH AMINES

By J. W. JORDAN

U.S.A.

ABSTRACT

Amine-bentonite complexes have been prepared and a study made of alteration of the affinities of the bentonite in connection with various liquid systems. Several techniques were employed in observing the change in the clay from its naturally occurring condition to one in which it is compatible with organic liquids. A mechanism is proposed to account for the pronounced modification of characteristics.

SUI RAPPORTI FRA DIABASI ED ARGILLE DELLA FORMAZIONE ARGILLOSCISTOSA APPENNINICA. ESPERIENZE ED OSSERVAZIONI

Por P. GALLITELLI

Italy

RIASSUNTO

(*Published in full in* Clay Minerals Bulletin, no. 3, pp. 91-95, 1949.)

Prendendo lo spunto dalle osservazioni di Eugenia Montanaro Gallitelli sulla probabile origine di alcuni lembi della formazione argilloscistosa appenninica da rocce diabasiche, sono state istituite serie di esperienze per studiare l'alterabilità dei diabasi. Si è per questo trattata lungamente la polvere del diabase: (1) a pressione ed a temperatura ordinaria con acqua distillata satura di CO_2: (2) a 180-200 atmosphere e a 270° di temperatura in bombole chiuse con H_2O e CO_2. In ognuna di queste esperienze si è potuto notare che l'alterazione del diabase porta sempre a un residuo microcristallino notevolmente più ricco in allumina della roccia di partenza, che presenta tutti i caratteri di una argilla.

Ricerche spettrografiche condotte sulle argille inglobanti le ofioliti hanno dimostrato la presenza in esse degli stessi constituenti minori tipici del diabase e del suo prodotto argilloso di alterazione: in altre argille appenniniche, originatesi per dilavamento subaereo, mancano invece alcuni dei costituenti minori tipici delle rocce diabasiche.

Ricerche ottiche e roentgenografiche sulla parte più fine delle argille hanno dimostrato che nella formazione argilloscistosa appenninica compaiono argille diverse, illitiche ed anche caoliniche.

DISCUSSION

In reply to a question from R. M. S. Robertson, P. Gallitelli said that typical elements of the diabasic rocks (Sc and Yb) were found in the phyllitic clays, whereas they were absent in the alluvial clays; this suggested that the former clays contained break-down products of the rocks. The whole untreated rock powder was used for the spectrographic determinations, and the complicated spectrograms obtained were not suitable for quantitative determinations.

In reply to F. E. Wellings, he replied that the exotic sedimentary blocks in the clay were of various formations and ages; the clays themselves could not be exotic, because (among other reasons) the microfossil shells were profoundly impregnated and obliterated by the clay material.

S. Hénin enquired about the influence of pH on the artificial weathering process, and was informed that weakly alkaline solutions produced a more rapid initial solution of silica. The products formed in this type of attack had not yet been investigated.

A TRIOCTAHEDRAL MONTMORILLONITE DERIVED FROM BIOTITE

By D. M. C. MacEWAN
Great Britain

ABSTRACT

In a Scottish soil derived from olivine-norite there occur flakes of weathered biotitic material, each of which is an aggregate of minute crystallites of a trioctahedral montmorillonite. The composition of this material resembles that of vermiculite and gives the formula

$$(Si_{6\cdot17}\, Al_{1\cdot83})^{IV}\, (Al_{0\cdot89}\, Fe^{+++}_{1\cdot37}\, Fe^{++}_{0\cdot30}\, Mg_{3\cdot00}\, Ca_{0\cdot24})^{VI}\, O_{20}\, OH_4 + M^{+}_{0\cdot40},$$

corresponding to a base exchange capacity of 84 m. eq./100 gm. This material accounts for an abnormally high base exchange capacity in the silt and sand of the soil.

DISCUSSION

D. B. Honeybourne asked if exchangeable cations were held between the layers of this mineral as in dioctahedral montmorillonite, and wondered how they could penetrate to the interior of the aggregates. D. M. C. MacEwan, in reply, presumed that they were, and said that since interlamellar glycerol saturation was so easy to achieve, the structure of the aggregates must be an open one.

G. F. Walker reported the fairly widespread occurrence of similar material in the North-east of Scotland. It appeared in general to occur in poorly drained soils from basic and ultra-basic rocks, being replaced by a vermiculitic mineral in freely drained soils.

In connection with the question of the origin of the abundant biotitic flakes in such weathered basic rocks, I. Stephen reported the weathering of hypersthene in norite to a hydrated trioctahedral mica, which had been observed optically and by X-rays.

THE OCCURRENCE OF DICKITE IN SOME SEDIMENTARY ROCKS

By J. E. HEMINGWAY and G. W. BRINDLEY
Great Britain

ABSTRACT

The occurrence of dickite is here recorded from Middle Jurassic rocks of north-east Yorkshire, in cracks and septaria in rocks of marine and deltaic origin, and replacing the shell-substance in a fossiliferous marine ironstone. X-ray examination shows it to occur both as pure, fairly coarse crystallites and mixed with varying amounts of kaolinite. Its distribution here and elsewhere invalidates the view that dickite is always of hydrothermal origin. Like kaolinite it may originate as a low-temperature mineral, presumably from decomposition of alumino-silicates.

The emplacement of dickite and kaolinite in cracks and as shell replacement, indicates migration through the rocks after their diagenesis, probably in solution and not as particles. The minerals are probably derived from the many poor underclays and weathered surfaces in the Middle Jurassic sequence. Large-scale migration of clay minerals, particularly through coarse-grained sedimentary rocks is undoubtedly common in late diagenesis, and explains the frequent occurrence of fresh detrital feldspar with interstitial kaolinite, presumably derived from decomposition of feldspars.

DISCUSSION

K. C. Dunham pointed out that the commonest paragenesis of dickite appeared to be in association with such minerals as blende and galena, even where hydrothermal origin was improbable, but J. E. Hemingway in reply said that the latter minerals were not found in the Ellen Beck Bed ironstone. In the Jurassic horizons, and the Yorkshire Coal Measures, when they occurred, kaolinite was usually the associated mineral. In reply to a further question of K. C. Dunham, J. E. Hemingway said that dickite was not found interstitially in coarse felspathic sandstones of the Millstone Grit of Yorkshire.

CONTRIBUTION TO THE STUDY OF THE SPANISH SLATES OF THE SILURIAN

By J. M. ALBAREDA, V. ALEIXANDRE and C. SANCHEZ CALVO
Spain

ABSTRACT

The study of the Spanish slates of the Silurian period has been initiated with a view to establishing their mineralogical constituents and determining the geochemical behaviour of the K^{+}, Ca^{++}, Mg^{++}, Sr^{++} and Ba^{++} ions. The techniques used for finding the mineralogical constituents have been the following: elemental chemical analysis, rational chemical analysis, total base-exchange capacity, adsorbed exchange cations, selective adsorption from mixed solutions of Cl_2Mg and Cl_2Ba, dehydration curves and thin rock sections.

In general, in the samples studied up to the present, we find quartz, muscovite and biotite in abundance, the other clay minerals in small quantities.

The amounts of ions in these slates allows us to come to some conclusions on the processes of clay adsorption. The contents of MgO are notably higher than those of CaO, which can be explained by the binding strength of the adsorption compound formed. The relation Sr/Ca has an average of 0·025, which represents an important enrichment in comparison with the average of eruptive rocks, which is 0·01. The relation Ba/Ca in slates oscillates around 0·07 as against 0·01 in eruptive rocks.

PHYSICOCHEMICAL STUDY OF CLAYS EXTRACTED FROM SPANISH SOILS

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ABSTRACT

Clay has been extracted from soils of different origin and developed under different climatological conditions, proceeding in such a way that from the extract three perfectly differentiated grain-size fractions were obtained. Each fraction has been analyzed. After the destruction of the organic matter by hydrogen peroxide and transformation into H-clay, curves of hygroscopicity, dehydration and neutralization, and the base-exchange capacity, have been determined. The differences between the three grain-size fractions of each soil have also been studied.

The gels were extracted by Dion's method and analyzed.

In clays without gels, the same properties have been analyzed and the differences between clays with gels and those without, as well as the mineralogical composition of each fraction, have also been studied.

MONTMORILLONITE IN GRANITIC PEGMATITES

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ABSTRACT

Montmorillonite occurs in Portuguese granitic pegmatites, partially replacing the orthoclase and microcline.

Such a replacement would have occurred through alkaline and magnesian hydrothermal solutions varying from 200° to 300° C. Under these conditions the feldspar would principally lose its alkalies and a part of silica, undergoing the inclusion of magnesium.

LIST OF THE PARTS OF THE REPORT OF THE EIGHTEENTH SESSION